AD-A084 713 WYOMING UNIV LARAMIE DEPT OF PHYSICS AND ASTRONOMY F/G 3/1
INFRARED STUDIES OF AFGL SOURCES.(U)
APR 80 R D GEHRZ, J A HACKWELL, G L GRASDALEN F19628-76-C-0271
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INFRARED STUDIES OF AFGL SOURCES

Robert D. Gehrz
John A. Hackwell
Gary L. Grasdalen

The University of Wyoming
Department of Physics and Astronomy
Laramie, Wyoming 82071

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Final Report
September 1976 - September 1979

14 April 1980

This research was supported in part by the Air Force In-House Laboratory Independent Research Fund

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AIR FORCE SYSTEMS COMMAND
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19 REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 18 AFGL-TR-79-0274	2. GOVT ACCESSION NO.: AD-A084713
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): 6 INFRARED STUDIES OF AFGL SOURCES.	5. TYPE OF REPORT & PERIOD COVERED: 9 Final Report. (9/76-9/79)
	6. PERFORMING ORG. REPORT NUMBER: Sep 76-Sep 79
7. AUTHOR(s): 10 ROBERT D. GEHRZ, JOHN A. HACKWELL, GARY L. GRASDALEN	8. CONTRACT OR GRANT NUMBER(s): 15 F19628-76-C-0271
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The University of Wyoming, Department of Physics and Astronomy, Laramie, Wyoming, 82071	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62101F; 16 767006AG; 17 06
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysical Laborotory, AFSC, Hanscom AFB, Massachusetts 01731, Monitor/Stephan Price/OPI	12. REPORT DATE: 11 14 Apr[redacted]80
	13. NUMBER OF PAGES: 57
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 57	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

same as above

18. SUPPLEMENTARY NOTES

This research was supported in part by the Air Force In-House Laboratory Independent Research Fund

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Infrared Astronomy, AFGL Sources, Sources of Galactic Radiation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The data acquired during the past three years form a promising base upon which to build a statistically complete analysis of the infrared objects populating our galaxy. Wyoming observations have also provided insight into the nature of new, and in some cases bizarre, classes of infrared sources which were discovered by the AFGL infrared survey. Many of these objects appear to represent important phases in the ongoing process of stellar birth and death.

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I. Summary

Since 1 July, 1976, the Wyoming Infrared Group has been under contract by Air Force Geophysical Laboratories (AFGL contract #F19628-76-C-0271) to conduct a continuing series of ground based infrared measurements of selected sources from the AFGL Infrared Catalog (Price and Walker, 1977).

The data acquired during the past three years form a promising base upon which to build a statistically complete analysis of the infrared objects populating our galaxy. It is clear that additional measurements are required to complete this task. Wyoming observations have also provided insight into the nature of new, and in some cases bizarre, classes of infrared sources which were discovered by the AFGL infrared survey. Many of these objects appear to represent important phases in the ongoing process of steller birth and death. Further ground based studies of these sources can be expected to clarify their role in the timeless scenario of stellar evolution.

We summarize in section II the accomplishments made under contract AFGL F19628-76-C-0271. The Appendices contain listings of data acquired during this program and reprints of publications that have resulted to date.

II. Accomplishments During the Past Three Years

During the contract period, measurements of AFGL sources were made with Ga - Ge bolometer photometers constructed with AFGL funds. These photometers respond at effective wavelengths of 2.3, 3.6, 4.9, 8.7, 10, 11.4, 12.6, 19.5, and 23μ and are equipped with helium cooled aperture wheels. Observations were obtained using the KPNO 50" telescope, the UM-UCSD 60" telescope and (since November, 1977) the 92" Wyoming Infrared Telescope. About 30% of the clear time available at the Wyoming Infrared Observatory (WIRO) was used in support of measurements for AFGL. AFGL funds supported, in part, the construction of the data acquisition electronics hardware for the Wyoming Telescope.

About half of the 1000 AFGL sources in the Wyoming Right Ascension zone (20^m - 40^m) and accessible from WIRO have either been searched for at 5, 10, or 20μ without confirmation or have been located and measured from 2.3 - 23μ. These data have led to several interesting results.

A. Completeness of the AFGL Catalog and the Composition of the Infrared Sky

The data sample acquired to date allows us to form some preliminary conclusions regarding the completeness of the AFGL Infrared Catalog and the infrared composition of the sky.

Cross-correlation of ground based magnitudes and AFGL magnitudes using our limited sample suggests that the AFGL catalog is complete to [4μ] = +1.3, [11μ] = -1.5, and [20μ] = -4.0. Using these magnitude limits to eliminate spurious sources, the AFGL objects we have surveyed appear to fall into two distinct populations. The first is a component which was detected by AFGL at 4μ only. Sources in this group have a high rate of successful cross identification with IRC and SAO stars as well as a rather small mean [4.9] - [11.4] color of ~0.5 [see figure 1a)]. Thus, the "4μ only" sources are probably associated with the normal cool stellar giant-supergiant populations in the galaxy.

The second population consists of sources detected by AFGL at 11μ and/or 20μ. Not only are there many more of these sources than there are "4μ only" sources at a given limiting magnitude but they tend to have extreme [4.9] - [11.4] colors [see figures 1b) and 2a) and b)]. We infer that a new population of very red (and/or cool) sources which contributes only marginally to the 4μ survey is present. Photometry of a selected sample of these "long λ" sources (see figures 3 and 4) suggests that a significant percentage of them may be associated with critical phases of star birth and death (Gehrz and Hackwell, 1976; Gehrz, Hackwell and Briotta, 1978; and Gehrz et al., 1979).

B. Studies of Peculiar Sources

We have made continuing observations of selected peculiar sources to achieve insight into their physical nature. A number of anonymous 10μ sources are currently being monitored for variability. At least one, GL 3099, appears to be a very large amplitude, long period, carbon rich variable (Gehrz, Hackwell, and Briotta, 1978).

GL 2636 has been shown to be a complex of new-born infrared stars in a region of possible shock-front induced star formation (see Gehrz et al., 1979).

The data obtained to date form a solid foundation upon which to build the important new observing programs which we propose in section III.

References

Gehrz, R. D. and Hackwell, J. A., 1976, Ap. J. (Letters), 206, L161.

Gehrz, R. D., Hackwell, J. A., and Briotta, D., 1978, Ap. J. (Letters), 221, L23.

Gehrz, R. D., Hackwell, J. A., Grasdalen, G. L., Merrill, K. M., Humpheys, R. M., Puette, R. C., Russell, R. W., and Willner, S. P., 1979, in preparation for Ap. J. Letters.

Figures

Figures 1a) and b):	[4.9] - [11.4] color index versus number of sources for the "4μ only" and "long λ" populations.
Figures 2a) and b):	Number density of sources versus limiting magnitude for all sources (a) and the "long λ" population (b). A uniform source distrubution would give a slope of 0.6.
Figure 3:	Five anonymous AFGL sources.
Figure 4:	The spatial energy distribution of AFGL 2636 at four wavelengths.

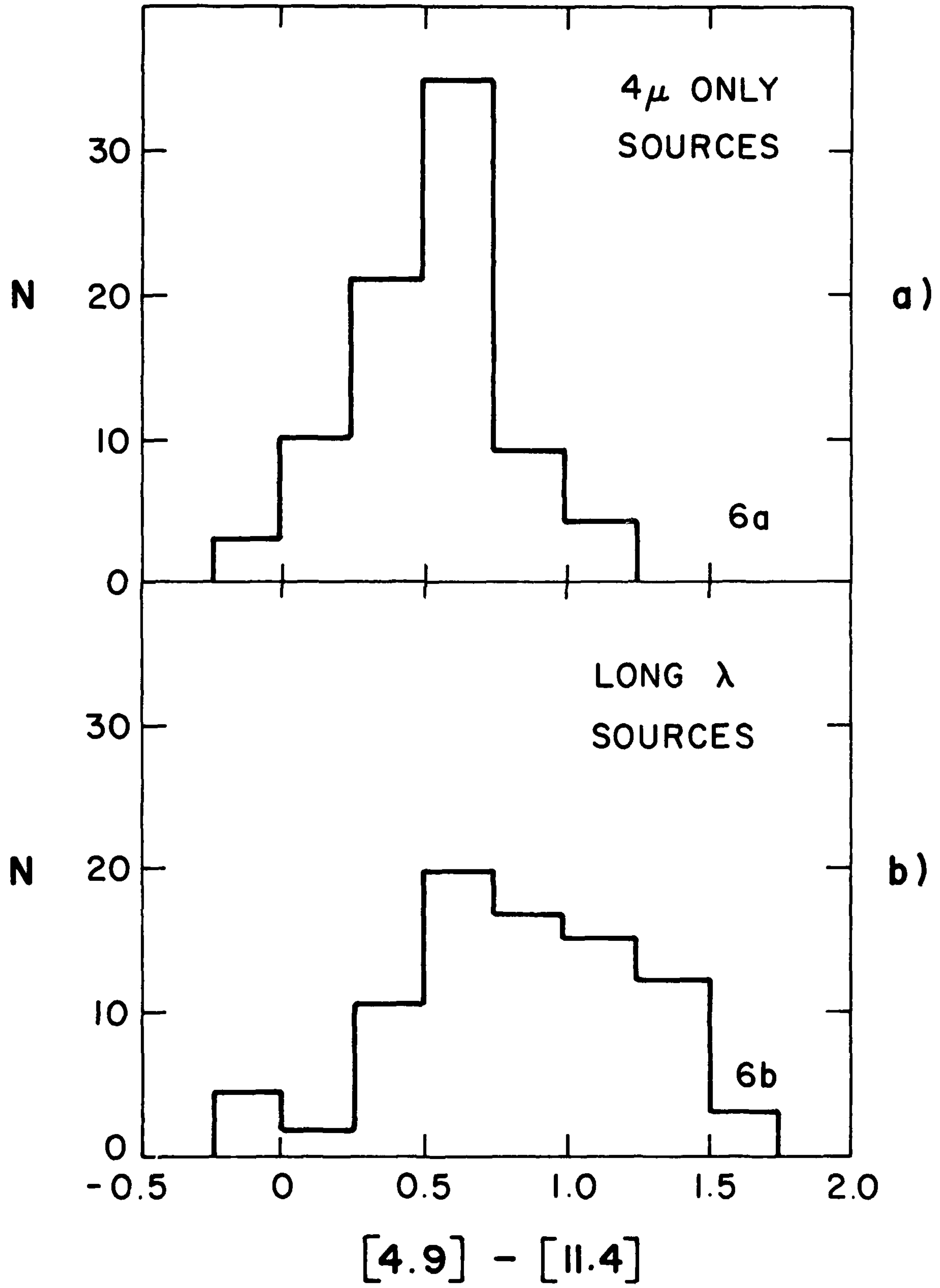
4μ ONLY
SOURCES
N
30
20
10
0
a)
6a
LONG λ
SOURCES
N
30
20
10
0
b)
6b
-0.5
0
0.5
1.0
1.5
2.0
[4.9] - [11.4]

FIGURE 1.

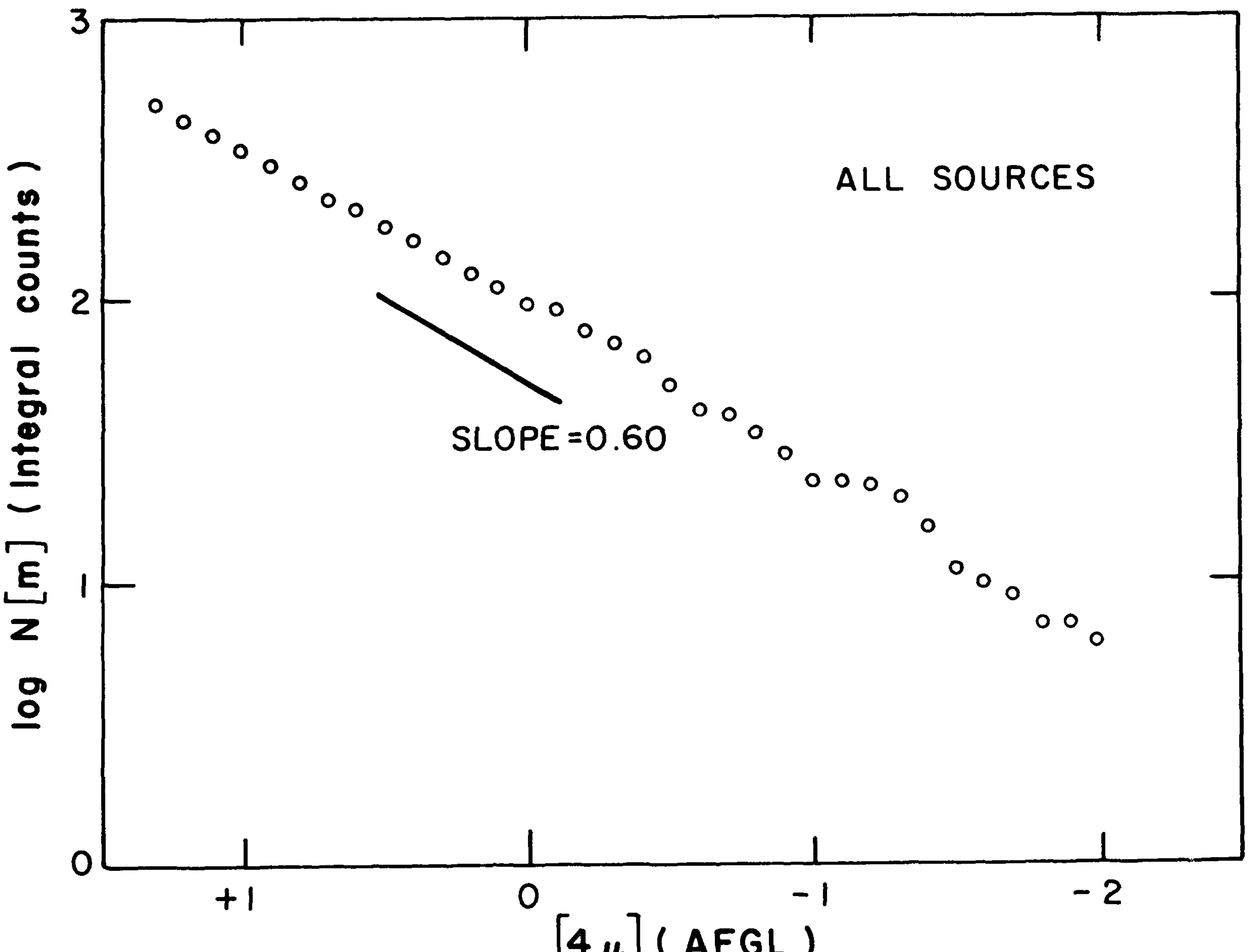
3
2
1
0
log N[m] (Integral counts)
ALL SOURCES
SLOPE=0.60
+1
0
-1
-2
[4μ] (AFGL)

FIGURE 2a)

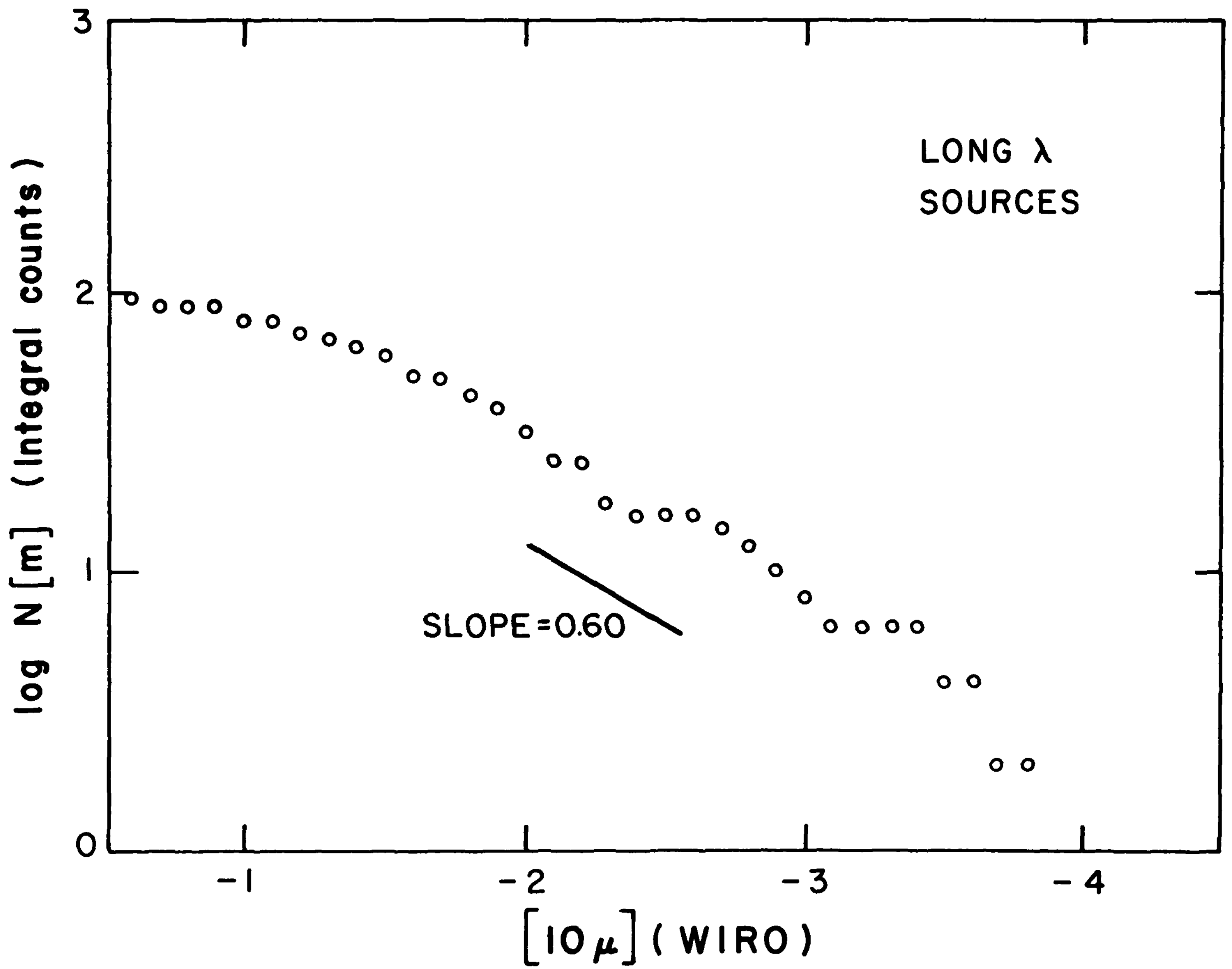
3
2
1
0
log N[m] (Integral counts)
LONG λ
SOURCES
SLOPE=0.60
-1
-2
-3
-4
[10μ] (WIRO)

FIGURE 2b)

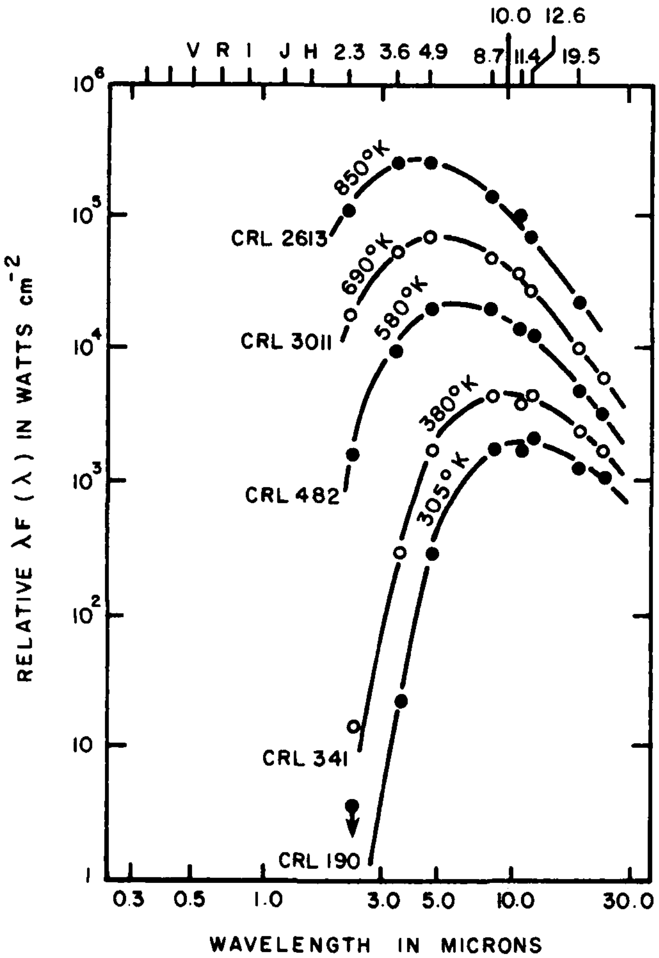
10.0 12.6
V R I J H 2.3 3.6 4.9 8.7 11.4 19.5
10^6
10^5
10^4
10^3
10^2
10
1
850°K
690°K
580°K
380°K
305°K
CRL 2613
CRL 3011
CRL 482
CRL 341
CRL 190
RELATIVE λF (λ) IN WATTS cm^{-2}
0.3 0.5 1.0 3.0 5.0 10.0 30.0
WAVELENGTH IN MICRONS

FIGURE 3

APPENDIX A
Data Acquired During the Program

11-19-78 UT

OBJECT	AM	BEAM	GL#	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
Nova Cyg 78	1.18	1.5mm		+5.66	+3.70	+2.74	+2.06	+2.06	+2.02	+1.86	+2.14	
RTLAC	1.27	1.5mm		+6.00	+5.91	+5.91		+5.92				
R PSC	1.33	1.5mm	226	+2.30	+1.66	+1.36	+0.78	+0.55	+0.22	+0.30	-0.06	+0.30
R FOR	2.6	1.5mm	337	+ .90	-0.20	-0.75	-1.80	-1.80	-2.30	-2.00	-1.86	
BABY STAR	1.06	1.5mm		+7.09	+4.93	+3.64	+2.20	+1.92	+1.75	+1.10	-1.55	-2.57
BABY STAR	1.11	3 mm		+6.89	+4.79	+3.44	+1.95	+1.68	+1.53	+0.71	-1.63	-2.76
CQ Aur	1.02	1.5mm		+6.48	+6.46	+6.27		>+6.33				
S CMi	1.20	1.5mm	1138	+0.56	-0.05	-0.16	-0.71	-0.94				

11-21-79 UT

OBJECT	AM	GL#	VAR	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
OH45.5-0.0	1.65			+8.41	+4.89	+3.19	+1.46	+1.26	+0.90	+0.59	-0.36	+0.34
OH42.3-0.2	2.10				+7.78	+4.64	+1.44	+1.32	+1.61	+0.24	-0.79	-1.28
BAnd	1.04			-1.95	-2.09	-1.89	-2.05	-2.04	-2.14	-2.06	-2.07	-2.09
SV AQR	1.70	3083		+1.22	+0.86	+0.79	+0.36	+0.09	-0.40	-0.29	-0.84	-0.37
GL 3086	2.28	3086		+1.25	+1.19	+1.12	+1.16	+1.25	+1.05	+1.47		
GL 3093	2.35	3093		+0.90	+0.95	+0.91	+0.72	+0.91	+0.67	+0.71		
GL 3087	1.11	3087		+1.59	+1.43	+1.55	+1.70	+1.62	+1.55	+1.68		
GL 3090	1.13	3090		+0.71	+0.50	+0.75	+0.55	+0.57	+0.45	+0.55	+0.28	
GL 3107	1.12	3107		+2.03	+1.83	+1.91	+1.77	+1.85	+1.61			
BAnd	1.01			-1.88	-2.08	-1.87	-2.03	-2.07	-2.14	-2.04	-2.14	-2.11
UX ARI	1.06			+3.74	+3.56	+3.61	+3.54	+3.54	+3.39		+3.66	
HR 1099	1.33			+3.14	+3.00	+2.94	+3.04	+3.03				
GL 606	1.10	606	TCAM	+0.61	+0.24	+0.41	+0.01	-0.02	-0.21	-0.17	-0.42	-0.03
BZTAU	1.22	619		+2.39	+1.65	+1.21	+0.65	+0.28	-0.13	-0.17	-0.91	

12-27-78 UT

OBJECT	AM	GL#	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
Nova Cyg 78	1.69		+7.57	+5.54	+4.57		+3.06			≥+1.87	
SW MON	1.24		+2.89	+2.66	+2.66	+2.40	+2.21	+1.93		+1.41	
CRGEM	1.15		+1.44								

5-16-79 UT

OBJECT	AM	GL#	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
GL 1686	1.56	1686	+2.49	+1.48	+0.99	-0.54	-0.95	-1.88	-1.68	-2.64	
GL 1822	3.2	1822		+3.09	+1.22						
OH 35.6-0.3	1.5										

7-26-79 UT

OBJECT	AM	GL#	10μ (N)
αLYR	1.00		+0.01
GL 2154	1.53	2154	-2.23
GL 2155	1.08	2155	-2.60
GL 2174	1.68	2174	-0.29
αLYR	1.07		-0.06
GL 2350	1.25	2350	-1.50
GL 2789	1.01	2789	-1.14
GL 3099	1.20	3099	-2.06

7-27-79 UT

OBJECT	AM	GL#	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
αLYR	1.25		-0.02	-0.03	+0.05	-0.02	-0.04	-0.03	-0.05	-0.07	
GL2350	1.64	2350	+3.66	+0.90	+0.95	-0.81	-1.28	-1.69	-1.69	-2.37	
GL2316	1.92	2316	+5.89	+2.75	+1.44	-0.25	-0.52	-0.81	-1.11		
GL2290	2.21	2290	+5.76	+1.94	+0.51	-1.46	-1.61	-1.81	-2.31	-2.29	
GL2428	1.39	2428	+5.04	+2.82	+1.69	+0.39	+0.11	-0.11	+0.01	-0.24	
αLYR	1.77		-0.05	-0.03	+0.02	-0.08					
βPEG	1.06		-2.25	-2.45	-2.37	-2.47		-2.57	-2.57	-2.69	
GL2789	1.17	2789	+4.94	+2.42	+1.04	-0.57	-1.03	-1.18	-1.73	-2.75	
GL3099	1.23	3099	+6.50	+2.63	+0.60	-1.57	-1.97	-2.26	-2.42	-2.80	-3.22
GY37,HII#1	1.16						+4.14				

8-30-79 UT

OBJECT	AM	GL#	BEAM, THROW	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
αLYR	1.01		5",10"	-0.03	-0.03	-0.05	-0.05	-0.02	+0.02	+0.05		
GL1954	2.21	1954	" "	+2.82	+1.88	+1.44	+0.32	-0.20	-0.81	-0.71	-1.17	
GL2023	2.75	2023	" "	+5.35	+1.77	+0.25	-1.54	-1.80	-2.25	-2.52	-1.87	
νSGR	1.84		" "	+2.35	+1.10	+0.36	-0.56		-1.37	-1.49		
αLYR	1.01		" "	-0.01	-0.01	-0.08	-0.02	-0.03	-0.06	-0.06		
HD200775	1.14		5",7.3	+4.64	+3.47	+2.91	+1.98	+1.76	+1.49	+1.42	+0.75	
HD200775	1.15		5",23"	+4.66				+1.76			+0.41	
GL2192	2.88	2192	5",10"	+2.65	+1.47	+0.88		-1.18				
GL2425	2.58	2425	" "	+2.48	+1.71	+1.13		-0.86	-1.49			
V337AQL	2.05		" "	+7.62								
GL2290	1.90	2290	" "	+5.82	+1.88	+0.30		-1.61	-1.91			
GL2316	1.83	2316	" "	+5.83	+2.83	+1.34		-0.45	-0.86			
βLYR	1.49		" "	+2.90	+2.73	+2.56	+2.37		+2.17			
αLYR	1.56		" "	+0.02	+0.02	-0.11	-0.02	-0.02	-0.15	-0.14		
βPEG	1.03		" "	-2.25	-2.49	-2.24	-2.46	-2.52	-2.60	-2.64	-2.80	
V448CYG	1.00		" "	+7.06	+7.00			+6.19				
GL2428	1.66	2428	" "	+4.90	+2.65	+2.01	+0.58	+0.14	-0.26	-0.02		
GL3099	1.29	3099	" "	+7.08	+2.97	+0.38	-1.68	-2.10	-2.42	-2.57	-3.15	
BM CAS	1.12		" "	+6.81	+6.11	+6.30						

10-4-79 UT

OBJECT	AM	GL#	BEAM, THROW	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
αLYR	1.12		5",10"	-0.06	-0.13	-0.16	-0.12	-0.13	-0.06	-0.07		
HD200775	1.13		5",10"	+4.73	+3.62							
HD200775	1.14		5",40"	+4.62	+3.60	+2.86	+1.98	+1.71	+1.57	+1.61	+0.55	
βPEG	1.03		5",40"	-2.24	-2.41	-2.24	-2.45	-2.49	-2.54	-2.55	-2.78	-2.78
βPEG	1.06		5",10"	-2.27	-2.44	-2.25	-2.38	-2.45				
GL3099	1.18	3099	5",10"	+5.71	+2.03	+0.10	-1.95	-2.22	-2.57	-2.74	-3.15	-3.45
GL2789	1.18	2789	5",10"	+4.73	+2.37	+1.01	-0.61	-0.98	-1.21	-1.79	-2.99	-3.43

	OBJECT	BEAM	THROW	DATE	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
GL4029	BABY STAR	4.5"	10"	19 NOV 78	+7.09	+4.93	+3.64	+2.20	+1.92	+1.75	+1.10	-1.55	-2.57
GL4029	BABY STAR	10"	10"	19 NOV 78	+6.89	+4.39	+3.44	+1.95	+1.68	+1.53	+0.71	-1.63	-2.76
GL2695	HD200775	4.5"	9"	29 AUG 79	+4.70	+3.53	+2.35	+1.92	+1.72	+1.65	+1.82	+0.77	
GL2695	HD200775	4.5"	7.3"	30 AUG 79	+4.64	+3.47	+2.91	+1.98	+1.76	+1.49	+1.42	+0.75	
GL2695	HD200775	4.5"	23"	30 AUG 79	+4.66				+1.76			+0.41	
GL2695	HD200775	4.5"	10"	04 OCT 79	+4.73	+3.62							
GL2695	HD200775	4.5"	40"	04 OCT 79	+4.62	+3.60	+2.86	+1.98	+1.71	+1.57	+1.61	+0.55	

All measurements on WIRO 234 cm telescope with Wyoming photometers

Summary of 1977-1978 data

GL#	UT DATE	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
1780	04/04/78	+0.14	-0.39	-0.70	-1.13	-1.34	-1.83	-1.81	-2.13	
1482	04/04/78	+1.37	+1.17	+0.91	+0.94	+0.91	+0.27	+0.21	-0.02	
1868	04/04/78	+0.17	-0.21	-0.33	-0.68	-0.93	-1.84	-1.45	-1.73	
1431	04/05/78	+1.74	+1.59	+1.77	+1.68	+1.65	+1.52	+1.50	+1.41	
1423	04/05/78	+1.53	+1.16	+1.12	+0.56	+0.42	+0.03	-0.02	-0.25	
1258	04/11/78	+0.09	-0.28	-0.37	-0.78	-0.85	-1.02	-1.13	-1.34	-0.85
1253	04/11/78	+0.96	+0.65	+0.83	+0.27	+0.00	-0.28	-0.53	-0.89	
1250	04/11/78	+0.38	+0.10	-0.11	-0.97	-1.62	-2.19	-1.91	-2.57	-2.41
1355	04/11/78	+2.04	+1.82	+1.93	+1.21	+0.80	+0.37	+0.50	-1.01	-1.17
1403	04/11/78	+1.45	-1.55	-3.04	-4.40	-4.62	-5.03	-4.93	-5.05	-5.08
1411	04/05/78	-0.92	-1.06	-0.87	-1.00	-0.98	-1.09	-1.05	-1.10	-0.97
1862	04/19/78	+2.87	+1.90	+1.35	-0.01	-0.58	-1.15	-0.84	-1.92	-1.94
2316	06/11/78				-0.80		-1.40			
1274	06/12/78	+3.60	+1.96	+0.94	-0.43	-0.92	-1.48	-1.39	-3.09	-3.39
1686	06/12/78	+3.51	+2.24	+1.57	+0.16	-0.45	-0.85	-0.85	-1.94	-1.92
1642	06/12/78	+0.41	+0.22	+0.42	+0.26	+0.19	+0.07	+0.10	-0.19	
1643	06/12/78	+0.63	+0.52	+0.79	+0.66	+0.58	+0.65	+0.68	+1.05	
1788	06/12/78	-0.92	-1.26	-1.13	-1.48	-1.74	-1.94	-2.02	-2.65	-2.77
1792	06/12/78	+0.81	+0.67	+0.81	+0.72	+0.72	+0.52	+0.51	+0.74	
1852	06/12/78	+2.65	+2.57	+2.65	+2.59	+2.57	+2.66			
1822	06/12/78		+3.21			-1.05	-1.36	-2.00		
2428	06/12/78	+4.86	+2.71	+1.60	+0.35	+0.09	-0.14	-0.21	-0.39	
2789	06/12/78	+4.67	+2.25	+0.98	-0.60	-0.97	-1.26	-1.75	-2.86	
3099	06/12/78	+5.92	+2.19	+0.22	-1.83	-2.13	-2.56	-2.67	-2.95	
2425	06/12/78	+2.88	+1.96	+1.34	-0.26	-0.87	-1.44	-1.17	-2.05	
2350	06/12/78	+3.96	+1.90	+0.97	-0.66	-1.25	-1.71	-1.71	-2.53	
3099	06/18/78	+5.66	+1.96	-0.11	-2.11	-2.42	-2.71	-2.90	-3.33	-3.56
2789	06/18/78	+4.43	+2.01	+0.61	-0.93	-1.31	-1.56	-2.06	-3.51	-4.20
3125	06/18/78	+4.82	+4.49	-0.59	-1.04	-1.67	-2.23	-1.97	-3.05	-3.30
3116	06/18/78	+2.81	+0.02	-1.64	-3.32	-3.60	-3.98	-4.02	-4.71	-5.24
2428	06/22/78	+4.81	+2.59	+1.44	+0.32	+0.15	-1.18	-0.01		
2789	06/22/78	+4.60	+2.22	+0.94	-0.65	-0.95	-1.26	-1.77		
2199	06/23/78	+2.42	+0.51	-0.40	-2.20	-2.62	-2.93	-2.94	-4.03	
2155	06/23/78	+5.79	+1.66	-0.31	-2.52	-2.88	-3.21	-3.24	-3.85	
2154	06/23/78	+5.21	+1.66	+0.09	-1.61	-1.83	-2.14	-2.12		
2174	06/23/78	+4.12	+2.63	+1.68	+0.44	-0.22	-0.68	-0.98		
2178	06/23/78	+5.09	+1.50	-0.05	-1.77	-2.04	-2.34	-2.39	-2.39	
2192	06/23/78	+3.64	+2.02	+1.28	-0.30	-0.80	-1.20	-1.18		
2290	06/23/78	+6.05	+1.07	-0.54	-2.36	-2.48	-2.35	-2.50		
3099	06/23/78	+5.89	+2.12	+0.19	-1.83	-2.18	-2.50	-2.61	-3.20	
1686	08/04/78	+3.59	+2.21	+1.67	+0.32	-0.30	-0.69	-0.45		
1993	08/04/78	+0.85	+0.48	+0.75	+0.24	-0.57	-1.11	-0.77		
2148	08/04/78	+1.79	+1.06	+0.90	+0.44	-0.01	-0.26	-0.51		
1988	08/04/78	+0.98	+0.23	-0.17	-1.34	-2.01	-2.52	-2.26		
1922	08/04/78	+6.03	+1.94	+0.00	-2.14	-2.48	-2.92	-2.98		
2636	08/04/78	+10.45	+8.35	+6.38	+3.38	+2.87	+2.63	+2.05	-2.80	
2636	08/04/78	+7.16	+5.46	+4.21	+2.60	+2.28	+2.12	+1.55		
2428	08/04/78	+4.80	+2.59	+1.08	+0.21	-0.04	-0.46	-0.39	-0.39	

Summary of 1977-1978 data (continued)

GL#	UT DATE	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
3099	08/04/78	+5.92	+2.04	+0.10	-1.81	-2.22	-2.56	-2.68	-3.17	
2789	08/04/78	+4.60	+2.15	+0.69	-0.68	-1.19	-1.33	-1.89	-2.87	
2290	08/05/78	+4.17	+0.87	-0.72	-2.46	-2.60	-2.85	-3.42	-4.08	
2199	08/05/78	+2.50	+0.51	-0.43	-2.17	-2.31	-2.95	-3.03	-3.64	
2316	08/05/78	+4.37	+1.52	+0.12	-1.07	-1.26	-1.62	-1.93	-1.87	
2789	08/05/78	+4.45	+2.02	+0.73	+0.78	-0.99	-1.28	-1.97	-2.83	
2636	08/05/78					+2.35				
1686	08/16/78	+3.42	+2.00	+1.61	+0.27	-0.34	-1.04	-0.80	-2.09	
3099	08/16/78	+6.47	+2.50	+0.52	-1.62	-2.11	-2.41	-2.64	-3.39	
2789	08/16/78	+4.85	+2.42	+1.13	-0.49	-0.97	-1.24	-1.86	-3.40	
211	08/16/78	+2.53	+1.69	+1.35	+0.71	+0.22	-0.09	-0.21		
2181	08/17/78	+2.21	+1.87	+2.03	+1.92	+1.66	+1.48	+1.39		
2575	08/17/78	+0.10	-0.58	-0.61	-1.66	-2.67	-3.23	-3.24	-3.88	
2583	08/17/78	+1.53	+0.97	+0.89	+0.46	-0.02	-0.31	-0.47	-0.62	
2588	08/17/78	+0.43	+0.17	+0.35	+0.08	-0.15	-0.28	-0.15	-0.74	
2589	08/17/78	+0.99	+0.72	+0.97	+0.56	+0.35	+0.08	+0.25	-0.41	
2618	08/17/78	-1.08	-1.43	-1.23	-1.50	-1.63	-1.67	-1.81		
2754	08/17/78	+2.41	+1.78	+1.74	+1.29	+1.00	+0.78	+0.71	+0.42	
2934	08/17/78	+1.81	+1.45	+1.56	+1.17	+0.76	+0.44	+0.38	-0.17	
2940	08/17/78	+1.03	+0.78	+1.05	+0.82	+0.46	+0.23	+0.45	+0.15	
2943	08/17/78	+0.91	+1.59	+1.80	+1.43	+1.25	+0.99	+1.03	+0.94	
3088	08/17/78	+0.48	-0.06	-0.23	-0.81	-1.04	-1.39	-1.34	-1.71	
3010	08/17/78	+1.09	+0.77	+1.01	+0.64	+0.42	+0.21	+0.21	-0.30	
3085	08/17/78	+1.47	+0.80	+0.88	+0.02	-0.24	-0.70	-0.60	-0.84	
3110	08/17/78	+2.09	+1.50	+1.55	+0.36	-0.65	-1.13	-1.05	-1.93	
3125	08/17/78	+0.32	-0.02	-0.15	-0.58	-1.29	-1.76	-1.54	-2.32	
227	08/17/78	+2.13	+1.61	+0.86	+1.48	+1.44	+1.26			
335	08/19/78	+1.46	+0.78	+0.47	-0.01	-0.40	-0.78	-0.82	-1.35	-1.64
347	08/19/78	+0.02	-0.31	-0.12	-0.64	-1.15	-1.62	-1.56	-2.57	-2.66
350	08/19/78	+1.88	+1.55	+2.67	+1.26	+0.96	+0.59	+0.51	-0.25	
582	08/19/78	+1.46	+0.82	+0.89	+0.14	+0.03	-0.70	-0.37	-0.20	
1570	12/20/77	-0.53	-0.87	-0.88	-0.14	-1.51	-1.69	-1.84	-2.36	-2.19
1489	12/20/77	+0.55	+0.20	+0.19	-0.04	-0.26	-0.47	-0.74	-0.95	-0.92
1719	12/20/77	+0.04	-0.37	-0.42	-0.68	-1.19	-1.55	-1.65	-2.37	-2.40
1720	12/20/77	+0.37	+0.03	+0.29	+0.03	-0.42	-0.82	-0.70	-1.11	
748	12/21/77	+1.61	+0.35	-0.33	-1.26	-1.43	-1.69	-1.54	-1.40	
794	12/21/77	+0.66	+0.14	-0.11	-0.81	-1.34	-1.83	-1.78	-2.26	
802	12/21/77	+1.24	+0.61	+0.31	-0.19	-0.39	-0.81	-1.11	-1.23	
805	12/21/77	+0.99	+0.33	-0.08	-0.57	-1.02	-1.35	-1.46	-1.77	
934	12/21/77	+0.93	+0.68	+0.79	+0.29	+0.32	+0.04	+0.11	-0.20	
1354	12/21/77	+1.44	+1.18	+1.24	+0.74	+0.83	+0.34	+0.34		
1280	12/21/77	+0.49	+0.28	+0.35	-0.13	-0.58	-1.04	-1.00	-1.20	
1428	12/21/77	+1.07	+0.80	+0.80	+0.24	+0.07	-0.52	-0.62	-0.77	
1427	12/21/77	-0.40	-0.64	-0.57	-1.12	-0.90	-1.53	-1.63		
1488	12/29/77	+1.38	+1.11	+1.17	+0.62	+0.13	-0.33	-0.27	-0.93	-1.07
4157	12/29/77	+2.54	+2.01	+1.69	+1.07	+0.86	+0.63	+0.60	+0.35	
355	12/30/77	+1.13	+0.65	+0.39	-0.06	-0.21	-0.45	-0.43	-0.91	-0.95
505	12/30/77	+0.59	-0.03	+0.23	-0.88	-1.12	-1.50	-1.39	-1.53	
945	12/30/77	+1.22	+0.93	+1.01	+0.44	+0.00	-0.40	-0.33	-1.20	
583	12/30/77	+0.58	+0.35	+0.44	-0.06	-0.36	-0.74	-0.38	-1.43	-1.40
1120	01/21/78	-0.50	-0.80	-0.54	-0.95	-1.29	-1.68	-1.46	-2.16	-2.42

Summary of 1977-1978 data (continued)

GL#	UT DATE	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
601	02/17/78	-2.89	-2.96	-2.82	-3.00	-2.99	-3.08	-3.11	-3.10	-3.03
600	02/17/78	+1.54	+0.92	+0.78	+0.29	+0.03	-0.28	-0.55	-0.90	-0.81
761	02/17/78	+1.34	+1.11	+1.30	+0.93	+0.90	+0.68	+0.55	+0.18	+0.31
937	02/17/78	+2.53	+2.02	+2.45	+1.30	+1.26	+1.13	+0.99		
601	02/17/78	-2.87	-3.03	-2.82	-2.96	-2.94	-3.03	-3.04	-3.15	-3.24
788	02/17/78	+0.37	+0.03	+0.00	-0.45	-0.89	-1.27	-1.29	-2.01	-2.27
799	02/17/78					-0.41				
1163	02/17/78	+1.16	+0.88	+0.87	+0.51	+0.44	+0.27	+0.31	-0.04	
1117	02/17/78	+1.80	+1.49	+1.23	+0.68	+0.33	+0.03	-0.07	-0.52	-0.66
1183	02/17/78	-1.09	-1.19	-1.11	-1.23	-1.19	-1.20	-1.18	-1.32	-1.30
1281	02/17/78	-0.65	-0.76	-0.81	-1.22	-1.53	-1.84	-1.82	-2.10	-1.99
966	02/17/78	-0.58	-1.05	-0.92	-1.62	-1.75	-2.06	-1.92	-1.94	-2.02
982	02/17/78	+1.70	+0.93	+0.55	-0.31	-0.84	-1.33	-1.33	-1.62	-1.71
991	02/17/78	+1.57	+1.24	+1.34	+0.79	+0.81	+0.60	+0.63	+0.71	
998	02/17/78	+2.89	+2.62	+2.42	+1.84	+1.71	+1.49	+1.23	+1.50	
1693	02/17/78	-2.73	-2.73	-2.69	-3.00	-3.11	-3.01	-2.83	-2.88	-2.86
1554	02/17/78	-0.99	-1.33	-1.31	-1.64	-1.90	-2.26	-2.34	-2.62	-2.73
1693	02/17/78	-3.04	-3.16	-3.09	-3.29	-3.31	-3.36	-3.31	-3.32	-3.28
1706	02/17/78	-1.95	-2.36	-2.36	-2.90	-3.40	-3.74	-3.95	-4.34	-4.41
1710	02/17/78	+1.30	+0.52	+0.15	-0.63	-0.89	-1.24	-1.30	-1.91	-2.17
1693	02/17/78	-2.99	-3.12	-2.91	-3.02	-2.99	-3.07	-3.15	-3.08	-3.13
1773	02/17/78	+2.66	+1.34	+0.66	-0.74	-1.12	-1.61	-1.59	-2.27	-2.51
1858	02/17/78	+0.25	-0.50	-0.76	-1.41	-1.77	-2.16	-2.30	-2.54	-2.59
335	08/20/78	+1.46	+0.78	+0.47	-0.01	-0.40	-0.78	-0.82	-1.35	-1.64
347	08/20/78	+0.02	-0.31	-0.12	-0.64	-1.15	-1.62	-1.56	-2.57	-2.66
350	08/20/78	+1.88	+1.55	+2.67	+1.26	+0.96	+0.59	+0.51	-0.25	
582	08/20/78	+1.46	+0.82	+0.89	+0.14	+0.03	-0.70	-0.37	-0.20	
2688	09/26/78	+9.58	+6.91	+3.92	-0.93	-2.35		-3.18	-6.10	
1059	09/26/78	+3.43	+1.80	+0.67	-0.74	-1.34		-1.75	-3.53	
328	10/07/78					+1.25		+0.20		
4044	10/07/78	+2.24	+1.80	+1.83	+1.35	+1.03	+0.92	+0.83		
3099	10/20/78	+6.59	+2.54	+0.49	-1.68	-1.98	-2.42	-2.46	-3.05	-3.17
211	11/01/78	+2.25	+1.44	+0.92	+3.31	-0.09	-0.22	-0.35	-1.20	-1.74
216	11/01/78	+1.63	+1.32	+1.28	+0.76	+0.12	-0.30	-0.05	-1.20	-1.53
327	11/01/78	+1.78	+1.45	+1.51	+1.06	+0.77	+0.54	+0.45	-0.46	
332	11/01/78	+1.60	+1.00	+0.74	-0.26	-0.85	-1.42	-1.27	-2.09	-2.32
590	11/01/78	+1.35	+0.78	+0.63	+0.30	-0.01	-0.31	-0.31	-0.40	
604	11/01/78	+1.95	+1.77	+1.66	+1.40	+1.24	+1.18	+0.89	+1.06	
2636	11/02/78					+3.66				
203	11/02/78	+2.78	+2.32	+2.83	+2.62					
751	11/02/78	+1.81	+1.47	+1.72	+1.13	+0.74	+0.31	+0.66	-1.01	
796	11/02/78	+2.45	+1.65	+1.62	+0.45	+0.52	+0.29	+0.52		
341	11/02/78	+8.10	+5.11	+2.33	-0.48	-0.87	-1.16	-1.42	-2.74	
482	11/02/78	+5.47	+2.15	+0.42	-1.40	-1.66	-1.94	-1.99	-3.02	
928	11/02/78	+1.90	+1.51	+1.47	+0.78	+0.00	-0.55	-0.35	-1.83	
4060	11/02/78	+2.44	+2.12	+2.13	+1.78	+1.43	+1.14	+1.11		
933	11/02/78	+2.55	+0.93	+0.15	-0.92	-1.02	-1.36	-1.15	-1.86	
935	11/02/78	+5.34	+2.73	+1.40	-0.16	-0.37	-0.78	-0.71	-1.54	
1059	11/02/78	+3.53	+1.78	+0.54	-0.80	-1.14	-1.38	-1.76	-3.75	
1108	11/02/78	+0.93	+0.62	+0.70	+0.55	+0.55	+0.47	+0.58		

Summary of 1977-1978 data (continued)

GL#	UT DATE	2.3μ	3.6μ	4.9μ	8.7μ	10μ	11.4μ	12.6μ	19.5μ	23μ
1131	11/02/78	+2.28	+0.77	+0.00	-0.82	-1.00	-1.36	-1.25	-2.30	
1169	11/02/78	+1.67	+1.28	+1.28	+0.86	+0.52	+0.18	+0.32		
1141	11/02/78	+1.70	+0.58	-0.14	-1.43	-1.86	-2.27	-2.03	-3.56	
1253	11/02/78	+0.80	+0.31	+0.41	-0.04	-0.21	-0.56	-0.52	-1.95	
3116	11/03/78	+2.51	-0.27	-1.78	-3.27	-3.44				
226	11/19/78	+2.30	+1.66	+1.36	+0.78	+0.55	+0.22	+0.30	-0.06	+0.30
337	11/19/78	+1.80	-0.10	-0.50	-1.60	-1.70	-2.10	-1.70	-1.30	-0.70
4029	11/19/78	+6.90	+4.80	+3.40	+2.00	+1.70	+1.50	+0.70	-1.60	-2.80
1138	11/19/78	+0.60	-0.10	-0.20	-0.70	-0.90				
3083	11/21/78	+1.40	+1.00	+1.00	+0.50	+0.20	-0.30	-0.20	-0.60	-0.20
3086	11/21/78	+1.50	+1.40	+1.50	+1.40	+1.40	+1.20	+1.70		
3093	11/21/78	+1.10	+1.20	+1.30	+1.00	+1.10	+0.90	+1.00		
3087	11/21/78	+1.60	+1.40	+1.60	+1.70	+1.60	+1.60	+1.70		
3090	11/21/78	+0.80	+0.50	+0.80	+0.60	+0.60	+0.50	+0.60	+0.30	
3107	11/21/78	+2.10	+1.80	+1.90	+1.80	+1.80				
606	11/21/78	+0.70	+0.30	+0.40	+0.00	+0.00	-0.20	-0.20	-0.40	+0.00
619	11/21/78	+2.50	+1.70	+1.30	+0.70	+0.30	-0.10	-0.10	-0.90	
793	12/17/78	+1.01	+0.58	+0.40	-0.05	-0.27	-0.45	-0.82	-1.42	-1.61
967	12/17/78	+1.97	+1.69	+1.72	+1.50	+1.08	+0.71	+0.22	+0.08	
968	12/17/78	+0.25	-0.01	-0.11	-0.37	-0.69	-0.71	-0.81		
970	12/17/78	+1.77	+1.53	+1.46	+0.97	+0.59	+0.57	+0.95	-0.22	
1118	12/17/78	+1.75	+1.28	+0.89	+0.35	-0.19	-0.24	-0.22	-0.91	-2.02
57	12/17/78	-1.02	-1.49	-1.51	-1.98	-2.31	-2.64	-2.83	-3.26	-2.88
68	12/17/78	+1.53	+1.09	+1.24	+0.78	+0.55	+0.28	+0.32	-0.22	
59	12/17/78	+0.52	-0.25	-0.71	-1.77	-2.19	-2.67	-2.70	-3.23	
220	12/17/78	+2.58	+2.43	+2.56	+2.38	+2.21	+1.89	+2.28		
485	12/17/78	+0.27	+0.07	+0.39	+0.14	+0.15	-0.02	-0.10	+0.79	
489	12/17/78	+1.61	-0.29	-1.41	-2.60	-2.75	-3.23	-3.13	-3.35	-3.67
595	12/17/78	+1.56	+0.09	-0.82	-1.75	-1.88	-2.37	-2.25	-2.37	-2.60
4047	12/17/78	+2.46	+2.33	+2.46	+2.62	+2.84	+2.24	+2.46	+1.35	
585	12/17/78	+2.88	+0.46	-0.79	-1.97	-2.05	-2.39	-2.69	-2.91	-3.15
746	12/17/78	+2.63	+2.63	+2.32	+1.67	+1.72	+1.11	+0.95	+0.80	
791	12/17/78	+2.93	+2.29	+1.31	-0.95	-1.21	-1.77	-1.88	-2.79	-3.16
956	12/17/78	+0.78	-0.28	-0.85	-2.21	-2.56	-3.29	-3.08	-3.83	-4.02
955	12/17/78	+3.76	+2.35	+1.48	-0.17	-0.55	-1.21	-1.16	-2.15	-2.23
985	12/17/78	+4.77	+2.52	+0.89						
1160	12/17/78	+1.70	+1.60	+1.94	+1.56	+1.56	+1.53	+1.48	+1.18	
1249	12/17/78	+1.61	+1.39	+1.68	+1.34	+1.73	+1.04	+1.09	+1.09	
1265	12/17/78	+1.69	+1.48							

APPENDIX B:

REPRINTS OF PUBLICATIONS

THE ASTROPHYSICAL JOURNAL, 206:L161–L164, 1976 June 15

A SEARCH FOR ANONYMOUS AFCRL INFRARED SOURCES

R. D. GEHRZ* AND J. A. HACKWELL*
Department of Physics and Astronomy, University of Wyoming
Received 1975 December 15; revised 1976 March 15

ABSTRACT

Ten of 47 anonymous AFCRL infrared sources were confirmed during a recent search. The confirmed sources could represent different stages in the evolution of a single class of stars. It is suggested that these objects might be related to disk population giants or to planetary nebulae.

Subject heading: infrared: sources

I. INTRODUCTION

A ground-based search for 47 anonymous infrared sources reported in the AFCRL Infrared Sky Survey (Walker and Price 1975) was conducted during 1975 October 23–27, using the 1.3 m telescope of the Kitt Peak National Observatory. The sources selected for the search have not been identified with any previously reported optical, infrared, or radio objects.

II. THE SEARCH AND OBSERVATIONS

The search was conducted using a Wyoming multifilter infrared photometer with 11″ diameter beams thrown 21″ between centers in declination.

The telescope was initially pointed to the AFCRL position of a source by offsetting from a nearby bright star whose astrometric coordinates were obtained from the SAO catalog. An $8' \times 8'$ box centered on the AFCRL position of the source was then searched by scanning the telescope in declination at a rate of 20″ per second. This scanning technique reduced the false detection rate due to spurious noise spikes since a characteristic bipolar signal with a phase determined by the scanning direction was produced by a cosmic source traversing the beams in the chopping direction. Redundancy in spatial coverage was introduced by stepping the telescope 7″ (7/11 beam diameters) in right ascension between successive declination scans.

The 1.1 s integration time produced by this scanning technique gave a signal to noise ratio of ~3 for +2.3 mag at 4.9 μ, +0.5 mag at 10 μ (*N* band), and −2.5 mag at 19.5 μ (*Q* band). Although the majority of the sources were searched for at 10 μ, a few were searched for at 4.9 μ or 19.5 μ if information supplied in the AFCRL catalog implied a higher likelihood of confirmation at these wavelengths.

When a confirmation was obtained, photometric coordinates for the AFCRL source were determined relative to the SAO offset star.

Broad band infrared photometry of the confirmed sources was obtained with the Wyoming multifilter photometer which responds at effective wavelengths of 2.3 μ, 3.6 μ, 4.9 μ, 8.7 μ, 10 μ (*N* band), 11.4 μ, 12.6 μ, 19.5 μ (*Q* band), and 23 μ. The bandpasses and calibration of the Wyoming photometric system have been discussed by Gehrz, Hackwell, and Jones (1974).

III. RESULTS

Ten anonymous AFCRL sources were confirmed during our survey. Photometric positions, AFCRL positions, and galactic coordinates for these sources are given in Table 1.

The infrared magnitudes of the confirmed sources are presented in Table 2. Alpha Lyrae (CRL 2208) and α Tau (CRL 601) were the calibration stars and the object IRC +70°012 (CRL 107) was observed for comparison. Where appropriate, blackbody temperatures and blackbody angular diameters of the sources are given in columns (11) and (12). Figures 1 and 2 show the observed energy distributions of the sources listed in Table 1.

The 37 anonymous AFCRL sources which were not confirmed by our search are listed in Table 3.

IV. THE LOW CONFIRMATION RATE

We were able to confirm only a small fraction (~20%) of the 47 anonymous CRL sources in our sample. In addition, our confirmed sources are confined to the galactic plane and have $|b^{II}| \lesssim 11°$. None of the 23 sources in our sample with $|b^{II}| > 11°$ were confirmed, and 14 of 24 sources with $|b^{II}| \lesssim 11°$ were not confirmed (see Fig. 1). Low (1973) reported a similar confirmation rate and galactic distribution for a different sample of anonymous sources taken from a preliminary version of the AFCRL catalog.

Our low confirmation rate does not appear to result from larger positional uncertainties than have been reported for AFCRL sources by Walker and Price (1975). Their rms (1 σ) positional error for known sources observed in the AFCRL survey is ~1′.5. The mean positional deviations of our confirmed sources from the AFCRL positions were only 0′.6 in declination (maximum 1′.1) and 0′.8 in right ascension (maximum 2′.1). Thus, we would have expected to find at least 95 percent of the anonymous sources in an $8' \times 8'$ box.

* Visiting Astronomer, Kitt Peak National Observatory which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

PHOTOMETRIC POSITIONS FOR CONFIRMED ANONYMOUS AFCRL INFRARED SOURCES

CRL No.	CRL α(1950)	CRL δ(1950)	Wyoming α(1950)*	Wyoming δ(1950)†	l^{II}	b^{II}
190	01ʰ14ᵐ26ˢ	+66°57′.2	01ʰ14ᵐ26ˢ.3	+66°58′08″	125	4
341	02 29 22	+57 49.8	02 29 21.1	+57 48 53	136	−2
482	03 18 39	+70 16.9	03 18 38.8	+70 16 47	135	11
799	05 37 56	+13 45.7	05 37 46.6	+13 46 45	192	−9
2613	20 34 09	+53 39.0	20 34 04.4	+53 38 57	91	8
2699	21 02 49	+53 08.9	21 02 42.9	+53 09 07	93	4
2881	22 16 37	+43 31.0	22 16 32.0	+43 31 45	96	−11
2901	22 24 04	+60 04.5	22 24 08.1	+68 05 25	106	2
2999	22 55 32	+58 33.6	22 55 39.5	+58 33 28	109	−1
3011	22 58 48	+64 02.8	22 58 29.7	+64 02 38	111	4

* Error in α: ±0ˢ.3.

† Error in δ: ±5″.

TABLE 2

INFRARED MAGNITUDES OF CRL SOURCES CONFIRMED BY THE UNIVERSITY OF WYOMING

CRL Number	2.3 μ	3.6 μ	4.9 μ	8.7 μ	10 μ (N)	11.4 μ	12.5 μ	19.5 μ	23 μ	T_{BB} (K)	Minimum Angular Diameter (milli-arcsec)	Remarks
						Calibration Stars						
2208	−0.02	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	9850	3	α Lyr
601	−2.86	−2.98	−2.81	−2.98	−2.97	−3.05	−3.07	−3.16	−3.16	3780	22	α Tau
						Comparison Source						
107	+2.96	+1.86	+1.31	+0.08	−0.40	−0.92	−0.79	−1.52	−1.33	...	...	1
						Newly Confirmed Sources						
190	≥10.0	+6.60	+2.81	−0.83	−1.34	−1.73	−2.22	−2.98	−3.53	305	150	
341	+9.96	+5.29	+2.40	−0.36	−0.72	−1.10	−1.48	−2.18	−2.47	380	74	
482	+5.31	+2.00	+0.27	−1.49	−1.61	−1.95	−2.14	−2.46	−2.64	580	57	
799	+3.53	+2.02	+1.20	+0.08	−0.08	−0.45	−0.44	−0.95	≥1.02	1100	11	
2613	+4.04	+1.74	+0.08	−0.35	−0.55	−0.77	−0.70	−0.72	...	850	20	
2699	+3.40	+1.31	+0.27	−0.88	−1.15	−1.51	−1.66	−2.07	−2.32	875	24	
2881	+2.77	+1.32	+0.54	−0.54	−0.55	−0.80	−0.80	−0.97	−1.33	1150	14	
2901	+3.83	+1.04	−0.36	−1.97	−2.18	−2.46	−2.69	−3.24	−3.44	655	56	
2999	+3.37	+1.87	+0.99	−0.77	−1.52	−2.14	−2.04	−3.32	−3.63	...		2
3011	+4.22	+1.73	+0.48	−0.89	−1.07	−1.41	−1.43	−1.63	−1.74	690	35	

REMARKS.—(1) Identified by Walker and Price 1975 as IRC +70 012. (2) Faint red star in position of this source.

Our 4.9, 10, and 19.5 μ fluxes for the confirmed sources are *in reasonable agreement* with the AFCRL data. The largest discrepancies are noted for sources which are near the AFCRL survey detection limit. It is difficult to make a strong case for large infrared variations in any of our confirmed sources on the basis of the available data.

It is possible that some sources were undetected by our search because of large amplitude variations short of λ = 19.5 μ. Extended low surface brightness sources would also have been undetected by our photometer. It seems highly improbable that these effects can entirely account for our low confirmation rate.

V. DISCUSSION

The energy distributions of the confirmed sources (Figs. 2 and 3) suggest that these objects may represent different evolutionary stages in a single class of stars. The objects CRL 107 and CRL 2990 exhibit a hot (1100–1500 K) 2.3–4.9 μ *continuum* with thermal emission from a cool optically thin silicate grain thermosphere dominating the 8.7–23 μ spectral region. They resemble the NML Tau objects described by Strecker, Ney, and Murdock (1973). The objects CRL 190, CRL 341, CRL 482, CRL 3011, and CRL 2613 are cool blackbodies. Presumably, these objects represent the extreme

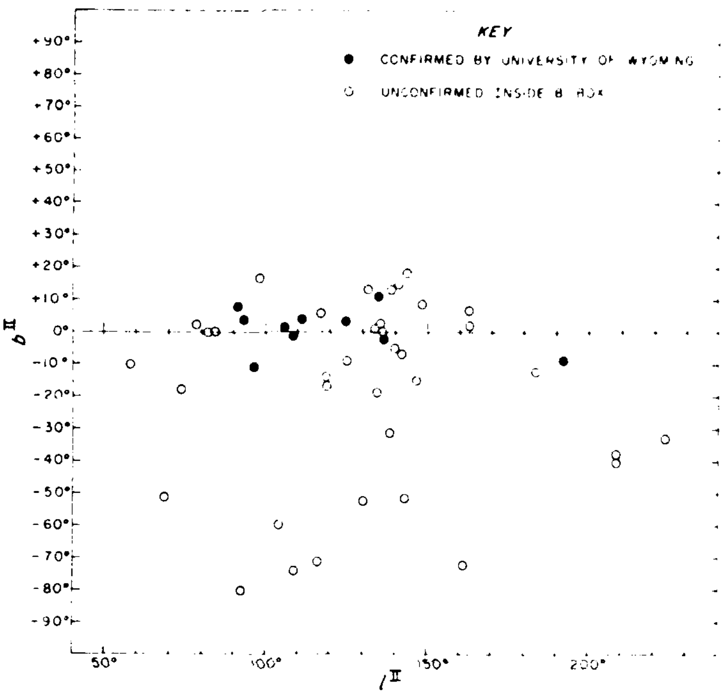

FIG. 1.—Galactic distribution of the anonymous AFCRL sources searched for in this survey. *Closed circles*, confirmed sources; *open circles*, sources which remained unconfirmed after a search in an 8' × 8' box.

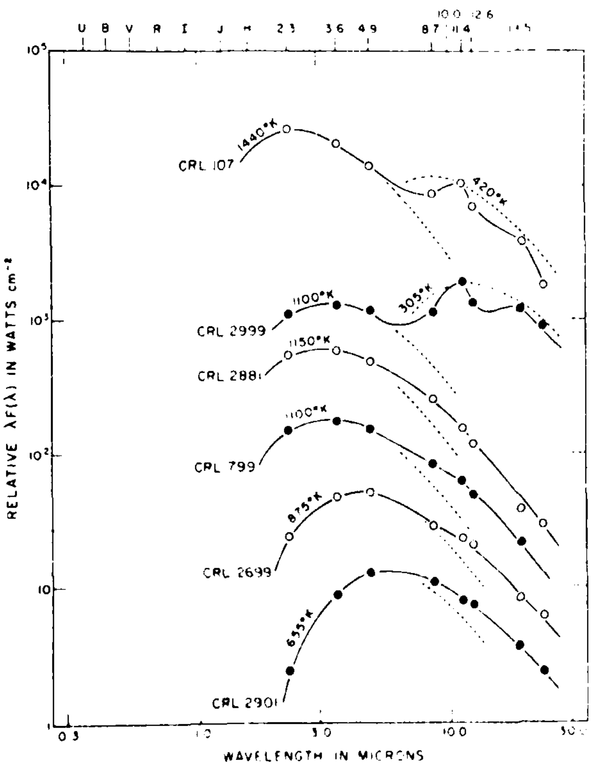

FIG. 2.—Energy distributions for CRL sources which show evidence of optically thin circumstellar shell radiation beyond λ = 8.7 μ.

case in which the exciting star is completely extinguished by an optically thick dust thermosphere.

The sources CRL 2901, CRL 2699, CRL 799, and CRL 2881 appear to represent an intermediate stage in the transition from an optically thin to an optically thick thermosphere. High-resolution 7–14 μ spectra of several of these sources (Gillett, private communication) suggest that the grain material in their thermospheres may contain silicon carbide.

It is interesting to note that the color temperatures of the optically thin thermospheres of CRL 107 (420 K) and CRL 2999 (305 K), deduced by assuming equal shell optical depths at 10 and 20 μ, are similar to the cool temperatures observed in the optically thick shells of CRL 190, CRL 341, and CRL 482.

The confirmed sources lie in the direction of the Perseus arm and have a mean $|b^{II}|$ of $\sim 6°$ (see Fig. 1). Their galactic latitude distribution is similar to that of the disk population giants and planetary nebulae (Allen 1973). If these objects lie in the Perseus arm at an average distance of 2–3 kpc, they will have an average luminosity of 1–2 × $10^4 L_{\odot}$. The luminosities of planetary nebulae and late-type luminous giants also lie in this range. Thus, these new infrared stars may be related to luminous giants or planetary nebulae. We suggest two alternative possibilities.

a) Cool luminous giants.—The new infrared stars may represent the advanced stages of evolution in cool luminous disk-population giants. These stars are known to be losing mass at a high rate (Gehrz and Woolf 1971). As evolution progresses, the optical depth of the dust thermosphere produced by the ejecta may eventually become sufficient to extinguish the exciting star. The

TABLE 3

ANONYMOUS CRL SOURCES UNCONFIRMED IN AN 8′ × 8′ BOX CENTERED ON CRL POSITION

CRL No.	Wavelength at which search was conducted	Probably Upper Limit to Flux (in magnitudes)
36	10	$N \geq +0.5$
63	10	$N \geq +0.5$
78	10	$N \geq +0.5$
81	10	$N \geq +0.5$
85	10	$N \geq +0.5$
105	5	$M \geq +2.3$
145	10	$N \geq +0.5$
166	10	$N \geq +0.5$
234	10	$N \geq +0.5$
244	10	$N \geq +0.5$
250	10	$N \geq +0.5$
331	10	$N \geq +0.5$
361	10	$N \geq +0.5$
368	10	$N \geq +0.5$
398	10	$N \geq +0.5$
399	10	$N \geq +0.5$
409	10	$N \geq +0.5$
546	10	$N \geq +0.5$
568	10	$N \geq +0.5$
574	10	$N \geq +0.5$
611	10	$N \geq +0.5$
620	10	$N \geq +0.5$
630	10	$N \geq +0.5$
680*	10	$N \geq +0.5$
687	10	$N \geq +0.5$
704	19.5	$Q \geq -2.5$
758	10	$N \geq +0.5$
785	10	$N \geq +0.5$
821	19.5	$Q \geq +2.5$
2510	10	$N \geq +0.5$
2530	10	$N \geq +0.5$
2579	10	$N \geq +0.5$
2616	10	$N \geq +0.5$
2631	10	$N \geq +0.5$
2760	10	$N \geq +0.5$
2954	10	$N \geq +0.5$
3154	10	$N \geq +0.5$

* CRL 680 was not detected at 11 μ by Walker and Price 1975.

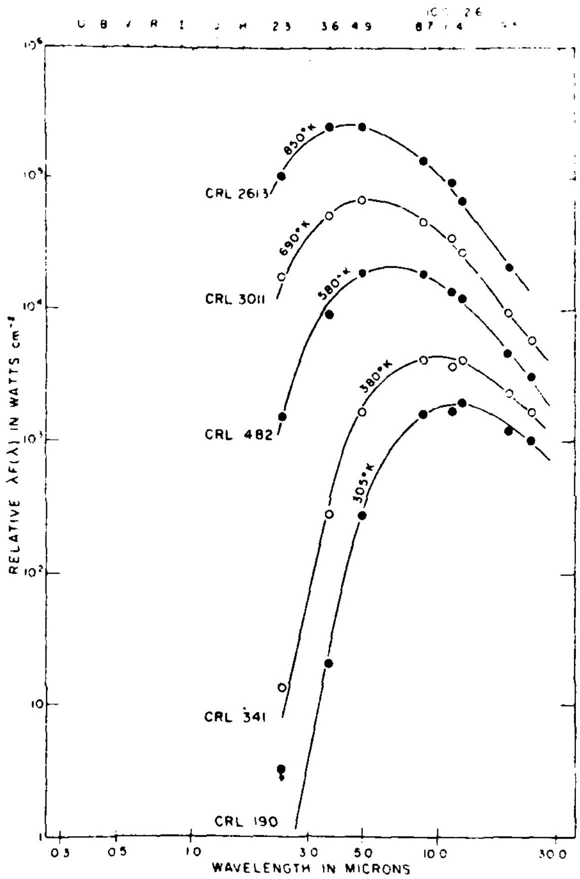

FIG. 3.— Energy distributions for CRL sources which appear to radiate like blackbodies from 2.3 μ to 23 μ.

energy of the embedded star will, in the extreme case, be entirely redistributed to the infrared by thermal reradiation from the dust.

b) Pre planetary nebulae. Alternatively, these sources could be a class of dust enshrouded objects which are evolving into planetary nebulae. Presumably the dust would have condensed as the outer layers of the star expanded during the final stages of nuclear burning. As the hot inner layers of the embedded star become exposed, an ionization front would move outward through the thermosphere, eventually vaporizing much of the dust and rendering the thermosphere optically thin.

The evolutionary status of these objects might be clarified if the spectral type of the embedded star could be determined.

We are indebted to F. C. Gillett and J. S. Gallagher for stimulating discussions concerning the nature of these sources. This work was supported by the National Science Foundation. Liquid helium for testing the photometer was supplied in part by the Office of Naval Research under contract N00014-61-C-0388.

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R. D. GEHRZ and J. A. HACKWELL: Department of Physics and Astronomy, The University of Wyoming, University Station, Box 3905, Laramie, WY 82071

THE ASTROPHYSICAL JOURNAL, 221:L23–L27, 1978 April 1

OBSERVATIONS OF THE HIGHLY EVOLVED CARBON STAR CRL 3099

R. D. GEHRZ,*† J. A. HACKWELL,*† AND D. BRIOTTA*†
Department of Physics and Astronomy, University of Wyoming
Received 1977 October 31; accepted 1978 January 6

ABSTRACT

Large-amplitude infrared light variations are reported for the peculiar infrared star CRL 3099. High-resolution ($\lambda/\Delta\lambda \sim 100$) 2.8–4.1 μm and 7.8–13 μm spectra suggest that CRL 3099 is a carbon star which is highly reddened by a dense circumstellar shell. Small graphite grains apparently are the primary opacity source for the circumstellar shell over the 4–20 μm spectral region. The grain temperature is ~360 K and the shell optical depth is ~0.1 at 10 μm. We suggest that CRL 3099 represents an advanced evolutionary stage which is characterized by the formation of large amounts of cool circumstellar dust and by large-amplitude bolometric variations in the central star. Objects similar to CRL 3099 may be a significant source of interstellar graphite.

Subject headings: infrared: spectra — stars: carbon

I. INTRODUCTION

Gehrz and Briotta acquired a faint 10 μm infrared source ([10 μm] = +1.68) with the University of Minnesota–University of California at San Diego (UM/UCSD) 1.5 m infrared telescope on JD 2,443,082 during a routine search for the anonymous infrared source CRL 3099. The source was reacquired at [10 μm] = +1.59 on JD 2,443,085. Photometric coordinates for this source of $\alpha(1950) = 23^h25^m43.5^s \pm 1^s$ and $\delta(1950) = 10°37'55'' \pm 15''$ were established by offsetting the telescope to SAO 108622.

A subsequent literature search revealed that a much brighter object ([10.4 μm] = −1.96) had been observed at the coordinates $\alpha(1950) = 23^h25^m45.0^s \pm 1^s$ and $\delta(1950) = \pm 10°38'14'' \pm 15''$ by Lebofsky *et al.* (1976). Joyce *et al.* (1977) reported more precise coordinates of $\alpha(1950) = 23^h25^m45.0^s \pm 0.33^s$ and $\delta(1950) = +10°38'08'' \pm 5''$ for the Lebofsky *et al.* source.

Additional observations during JD 2,443,207–2,443,210 by the Wyoming infrared group suggest that all of the aforementioned infrared observations were of a single pointlike infrared source. We conclude that very large-amplitude infrared variations, ranging from 4.7 mag in amplitude at 2.3 μm to 3 mag in amplitude at 20 μm, have been observed in CRL 3099. The consequences of these observations are discussed below.

II. THE OBSERVATIONS

Table 1 and Figure 1 summarize all known infrared photometric measurements of CRL 3099. Merrill and Ney communicated their JD 2,443,033 and 2,443,375 data to us prior to publication. The photometers and telescopes used to obtain the Wyoming photometry are indicated in the footnotes to Table 1.

High-resolution ($\lambda/\Delta\lambda \sim 100$) 2.8–4.2 μm and 7.8–13 μm spectra of CRL 3099 appear in Figure 2. The 2.8–4.2 μm spectra were obtained by using the KPNO "Autophot" InSb system with the KPNO 1.3 m telescope on JD 2,443,208. A Wyoming circular variable filter wheel spectrometer with a Wyoming 5-slit Ga:Ge bolometer was used on the 1.3 m telescope for the JD 2,443,210 7.8–13 μm spectrum. The 7.8–13 μm spectrum was taken about midday, and poor seeing caused the relatively large scatter in the data.

III. LARGE-AMPLITUDE INFRARED VARIATIONS IN CRL 3099

We conclude that the photometric data summarized in Table 1 demonstrate that CRL 3099 is a pointlike infrared source which varies substantially on a time scale of months.

The photometric positions determined for CRL 3099 by Lebofsky *et al.* (1976), Joyce *et al.* (1977), and ourselves are all consistent, within the quoted experimental errors, with the presumption that a single source was observed in all cases. All observers (see Table 1) have recorded infrared colors for the source which are in reasonable agreement with the colors reported for CRL 3099 by both the AFCRL (Walker and Price 1975) and AFGL (Price and Walker 1976) catalogs. Furthermore, we have searched a 6' box centered on the coordinates published by Joyce *et al.* (1977) at 5, 10, and 20 μm to a flux level of $\sim 5 \times 10^{-17}$ W cm^{-2} μm^{-1} and find only a single source to be present at these wavelengths.

We have ruled out the possibility that CRL 3099 is an appreciably extended source by comparing it with the point source 70 Peg at 3.45 μm and 4.63 μm, using beams subtending 22".6, 11".3, and 5".7 on the sky. These measurements show that CRL 3099 is pointlike to within the limits imposed by atmospheric seeing conditions. Thus, although the authors quoted in Table 1 have used a variety of beam sizes ranging from 3" to 30", it seems unlikely that the discrepant flux levels have resulted from instrumental effects.

* Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

† Visiting Astronomer, UM/UCSD, Mount Lemmon Infrared Observatory.

TABLE 1

CRL 3099 SUMMARY

	OBSERVER AND DATE (JD 244+)												
	AFCRL 1132	AFCRL 1335	AFCRL 1657	Lebofsky *et al.* 2710	Joyce *et al.* 2948	Merrill 3033	Gherz *et al.* 3082	Gehrz *et al.* 3085	Gehrz *et al.* 3207	Gehrz *et al.* 3208	Gehrz *et al.* 3209	Allen *et al.* unknown	Ney 3375
Telescope	...	...	...	...	...	...	UM-USCD 1.5 m	UM-USCD 1.5 m	KPNO 1.3 m	KPNO 1.3 m	KPNO 1.3 m	...	
Photometer	...	...	...	...	...	...	*	*	†	†	*	...	
1.23 μm	...	...	...	...	...	...	...	...	...	...	...	+12.20	
1.66 μm	...	...	...	...	...	...	...	...	...	...	...	+9.20	
2.3 μm	...	...	...	+7.22	...	+6.80	+9.65:	...	...	+5.93	+6.09	+6.40	+7.2
3.6 μm	...	...	...	+1.70	...	+2.90	+6.38	+6.18	+2.52	+2.41	+2.47	+2.90	+3.3
4.0 μm	...	+1.43	+0.92	...	...	...	...	...	...	...	...	...	
4.63 μm	...	...	...	...	+1.30	...	...	...	+0.61	+0.58	...	...	
4.9 μm	...	...	...	−0.32	...	+1.30	+4.59	+4.64	...	...	+0.33	...	+1.62
8.7 μm	...	...	...	−1.49	...	−1.40	+1.84	+1.91	...	...	−1.60	...	−0.90
10 μm (N)	...	...	...	...	...	...	+1.68	+1.59	...	...	−1.88	...	
10.4 μm	...	...	...	−1.96	...	...	...	...	...	...	...	...	
10.6 μm	...	...	...	−1.90	...	−2.40	...	...	...	...	...	...	−1.60
11 μm	−1.79	−2.11	−1.85	...	...	...	...	...	...	...	...	...	
11.4 μm	...	...	...	−1.66	...	...	+1.40	+1.48	...	...	−2.23	...	
12.6 μm	...	...	...	...	...	−2.60	...	+1.47	...	...	−2.41	...	−1.80
19.5 μm (Q)	...	−3.14	...	...	...	...	...	+0.07	...	...	−2.19	...	

* Wyoming multifilter photometer (see Gehrz, Hackwell, and Jones 1974).

† KPNO "Autophot" InSb system.

In support of the variability hypothesis, we note that the collective photometry of observers other than ourselves suggests a light amplitude of $\sim$2 mag at 5 μm. The enormous flux variations from 2 to 20 μm suggested by our JD 2,443,082 and 2,443,085 observations are among the largest yet reported for an infrared star.

IV. DISCUSSION

The data suggest that CRL 3099 is a carbon star in an advanced stage of evolution.

A deep 3.07 μm absorption feature ($\tau_{abs} = 0.9$ with respect to the neighboring continuum) and a high-contrast 11.5 μm SiC emission feature appear in the spectrum of CRL 3099 (see Fig. 2). Merrill and Stein (1976*a*) have shown that the simultaneous appearance of these features is unique to carbon stars. Although some objects exhibit 3.07 μm water ice absorption, the CRL 3099 feature is clearly similar in shape to the 3.07 μm features in other carbon-rich CRL objects. We show the 2–4 μm spectra of the carbon-rich CRL sources 799, 3011, and 482 for comparison in Figure 2.

Merrill and Stein (1976*b*) have noted that short-wavelength emission from hot circumstellar dust ($T_{dust} \sim 1000$ K) washes out the 3.07 μm absorption

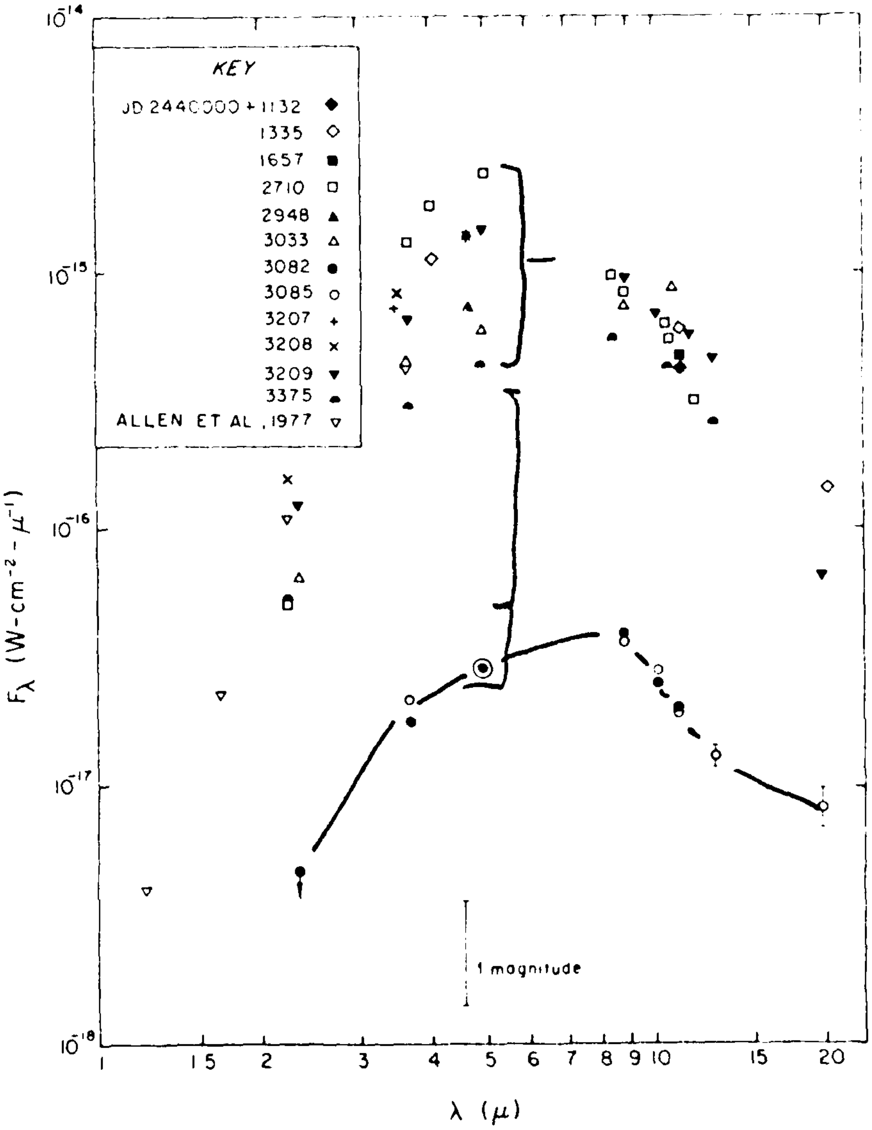

FIG. 1.—Photometric measurements of CRL 3099. The Wyoming data for minimum light are denoted by open and closed circles. Information concerning the remaining data and the plotting symbols are summarized in the figure and Table 1.

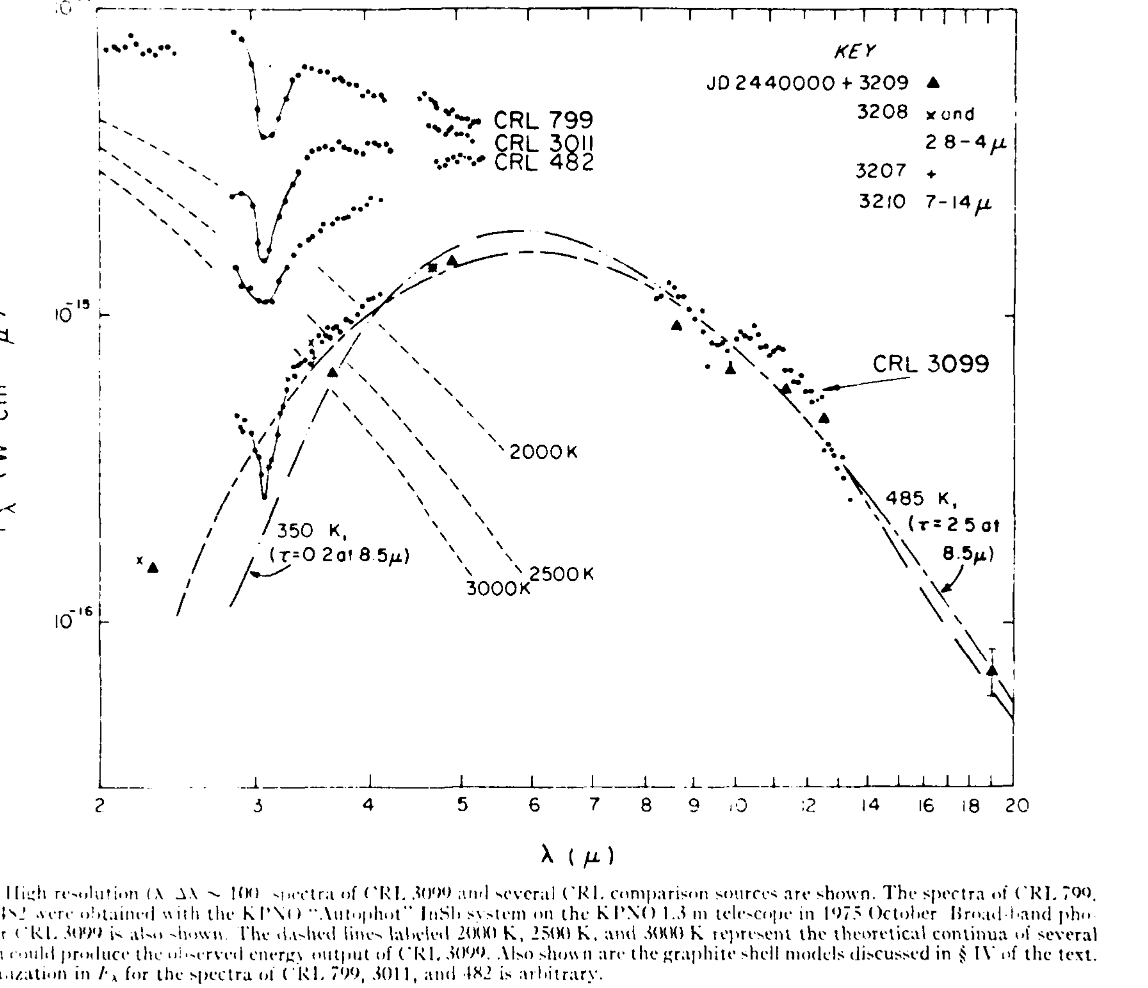

FIG. 2.—High resolution ($\lambda/\Delta\lambda \sim 100$) spectra of CRL 3099 and several CRL comparison sources are shown. The spectra of CRL 799, 3011, and 482 were obtained with the KPNO "Autophot" InSb system on the KPNO 1.3 m telescope in 1975 October. Broad-band photometry for CRL 3099 is also shown. The dashed lines labeled 2000 K, 2500 K, and 3000 K represent the theoretical continua of several stars which could produce the observed energy output of CRL 3099. Also shown are the graphite shell models discussed in § IV of the text. The normalization in F_λ for the spectra of CRL 799, 3011, and 482 is arbitrary.

feature in carbon stars such as IRC +10°216. The fact that the 3.07 μm feature in CRL 3099 is among the strongest yet observed is at least partially due to the cool (T_{gr} = 360 K) shell temperature which reduces shell emission at ~3 μm. Additionally, the constituents which produce this feature may exist in appreciable concentrations outside the shell.

Circumstellar emission from a cool shell composed of small ($a < 0.2$ μm) graphite grains provides a physically reasonable source for the ~3.5 to 20 μm continuum of CRL 3099. Two extreme model fits to this continuum are plotted in Figure 2. The first assumes a grain temperature, T_{gr}, of 480 K and a shell optical depth of $\tau_s = 2.5$ at 8.5 μm. The second assumes $T_{gr} = 350$ K and $\tau_s = 0.2$ at 8.5 μm. We assume that the opacity for small graphite grains is proportional to λ^{-2} over the region of interest (see Merrill and Stein 1976*a*; Gilman 1974*a*). Although SiC is in evidence from 10 to 12.5 μm, it is a negligible opacity source outside this spectral region compared with graphite (see Gilman 1974*a*). For both graphite shell models, it is seen that the radiation short of ~3 μm is probably dominated by the reddened stellar continuum.

CRL 3099 lies far out of the galactic plane ($b^{II} = -47°$) and should be subject to little, if any, interstellar reddening. Thus we propose that CRL 3099 is a "cocoon" star in which the observed reddening is caused almost entirely by a dense circumstellar shell. Assuming that the entire luminosity of a fairly "typical" carbon star ($T_* \sim 2000$–3000 K and $L \sim 10^3$–$10^4 L_\odot$) is being reradiated by a dense graphite shell, the data in Figure 2 imply an absorption optical depth of $\tau_* \sim 3$ at 2.3 μm for the graphite shell. This 2.3 μm optical depth is consistent with the small graphite grain model with $T_{gr} = 350$ K and $\tau_s = 0.2$ at 8.5 μm. We note that this model implies ~30 mag of visual extinction and ~10 mag of extinction at 1.25 μm. Not surprisingly, no optical counterpart to CRL 3099 has been reported and the $J - H$ and $J - K$ colors published by Allen *et al.* (1977) are comparable to those they observed in other invisible CRL sources. A shell radius of $\sim 3 \times 10^{15}$ cm was derived for the above model by using Gilman's (1974*b*) Planck mean cross sections for small grains. The 8.5 μm τ_s of 0.2, combined with Gilman's (1974*a*) graphite opacities, yields a graphite shell mass of $\sim 10^{-5}$ $M_\odot$. Thus, if the gas in the shell is ~ 250 times as abundant as carbon by mass (Allen 1973), the total shell mass is $\sim 3 \times 10^{-3}$ $M_\odot$.

The observation that CRL 3099 has a "cocoon" of considerable mass together with long-standing evidence for large mass loss in late-type stars (see Gehrz and Woolf 1971) leads us to speculate that CRL 3099 represents an advanced stage of evolution. Although "cocoon" stars are often exceedingly young objects, the extremely high galactic latitude ($b^{\rm II} = -47°$) of CRL 3099 places it morphologically among the oldest stars in the Galaxy. Amusingly, Lebofsky and Rieke (1977) have recently reported that CRL 3068, which also lies considerably out of the galactic plane ($b^{\rm II} = -40°$), is a carbon star enshrouded by a dense circumstellar shell. This star, too, varies in the infrared, although with a somewhat smaller amplitude than CRL 3099.

Although the data at minimum light (JD 2,443,082–2,443,085) do not yield detailed spectral information, the 5–13 μm continuum can be modeled by a small-grain graphite shell with $T_{gr} \sim 300$ K and $\tau_s \sim 0.2$ at 8.5 μm. The 20 μm point lies above this continuum, suggesting that some reasonable fraction of the shell luminosity may lie at long wavelengths at minimum light. A straightforward integration of the 2–20 μm flux as a function of time implies a bolometric variation in the luminous flux of a factor of 30. Even allowing for the possibility that a significant amount of energy may appear at wavelengths longer than 20 μm during minimum light, it is difficult to escape the conclusion that CRL 3099 is undergoing enormous bolometric changes. Extreme Mira variables are known to vary bolometrically by only a factor of 2–4 (Strecker 1973).

The time scale of months for the variation suggests pulsations of a relatively high density region ($\rho \sim 10^{-7}$ g cm^{-3}) such as the photosphere of the embedded star. We therefore presume that the infrared variations represent changes in the luminous output of the central star which are mirrored by the thermal emission of the surrounding "cocoon." It is possible that the star in CRL 3099 undergoes large-amplitude photospheric pulsations characterized by the mechanical deposition of large amounts of energy. These pulsations could drive large amounts of material into a dust-production zone, giving rise to the dense "cocoon." If we argue that CRL 3099 is radiatively extinguished for $\sim 10^7$ s, $\sim 10^{45}$ ergs must be stored mechanically. This could be accomplished by ionizing ~ 0.08 $M_\odot$ in hydrogen, which would represent only a small fraction of the mass of a typical carbon star.

In summary, we propose that CRL 3099 represents an advanced stage of carbon star evolution in which instability against large-amplitude pulsations enhances circumstellar dust formation and produces very large-amplitude bolometric variations. Because small graphite grains are extremely efficient absorbers of short-wavelength radiation, carbon stars similar to CRL 3099 will be virtually invisible to optical telescopes. We suggest that future far-infrared studies may reveal large numbers of objects like CRL 3099 and that mass loss from these objects could be a major source of interstellar graphite.

We thank K. M. Merrill and E. P. Ney for providing us with both insight concerning the physical nature of CRL 3099 and infrared photometry of it. K. DeGioia, D. McClain, and L. R. Shaw assisted with the observations. C. Sneden provided helpful comments. This research was supported by the US Air Force Geophysical Laboratories under Air Force contract F19628-76-C-0271 and by the National Science Foundation. Liquid helium for testing the photometers was provided, in part, by the Office of Naval Research under ONR contract N00014-71-C-0388.

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D. BRIOTTA, R. D. GEHRZ, and J. A. HACKWELL: Department of Physics and Astronomy, University of Wyoming, University Station, Box 3905, Laramie, WY 82071

On the Nature of the Peculiar Infrared Source AFGL 2636

by

R. D. Gehrz, J. A. Hackwell, and G. L. Grasdalen

Wyoming Infrared Observatory, Department
of Physics and Astronomy, the
University of Wyoming

K. M. Merrill and R. M. Humphreys

Department of Astronomy, School of
Physics and Astronomy, the
University of Minnesota

and

R. C. Puetter, R. W. Russell*, and S. P. Willner

Department of Physics, University
of California at San Diego

---

*Current address: Department of Astronomy, Cornell University, Ithaca, New York 14853

ABSTRACT

Infrared and visual observations suggest that AFGL 2636 is a region of star formation that is similar to the θ^1 - BNKL complex in the Orion Nebula. The geometrical position of AFGL 2636 within the Cygnus-X region may be an important clue to the processes which precipitated its formation.

I. Introduction

Price and Walker (1976) reported the discovery of a bright 20μ infrared source at the position $\delta(1950) = 20^h40^m42^s \pm 14^s$ and $\alpha(1950) = +42°46'.7 \pm 1.5$ which they designated GL2636 in their catalog. Gosnell, Hudson, and Puetter (1979) and K. M. Merrill (unpublished) subsequently verified the source and speculated that it was multiple because of their observation that the 2μ and 20μ emission peaks were slightly displaced.

We have recently used a small beam infrared photometer on the Wyoming Infrared Telescope to produce a set of isophotal maps of GL-2636 which confirm the presence of several point-like sources embedded in a small cool nebula. Our maps, together with additional infrared and visual data reported herein, suggest that GL2636 may be similar to the θ^1-BNKL complex in M42.

II. The Infrared Observation

Isophotal maps of GL2636 were produced at effective wavelengths of 3.6μ, 4.9μ, 10 (N band)μ, and 19.5(Q band)μ using a Wyoming Multifilter bolometer equipped with a 4.5"diameter circular beam (3.74×10^{-10} sr) at the Cassegrain focus of the 234 cm telescope of the Wyoming Infrared Observatory. The beams were thrown 33" between centers in declination to insure that the reference beam was always on blank sky. Gehrz, Hackwell and Jones (1974) have described the Wyoming photometric system.

Our maps, shown in Figures 1a)-d) reveal the presence of two point-like sources, which we have designated IRS1 and IRS2, embedded in a small cool nebula about 20" in diameter.

A variety of photometric and spectrophotometric measurements made to study the caracteristics of the GL2636 complex are described in Table 1 and Figures 2 and 3. Table 1 presents braodband 1.25-19.5μ measurements of the sources IRS1, IRS2 and a B1-2Ia supergiant that lies 15"S ±1" and 15" E ± 1" of IRS1. Columns 3, 4, and 5 indicate the photometer, telescope, and beam size for each measurement.

The 2% resolution 2-4μ spectrum shown in Figure 3 and first reported by Gosnell, Hudson and Puetter (1979), was produced using the UM-UCSD InSb system with a 17" beam on the UM-UCSD Mt. Lemmon 152 cm infrared telescope. The beam was centered on the GL2636 IRS1 source. Although the beam was quite large, comparison of the 2% spectrum with broadband 2.3μ and 3.6μ photometry of IRS1 suggests that contamination from other sources in the GL2636 complex and the nebula was less than 20%. We therefore conclude that the spectrum shown in Figure 3 is representative of IRS1.

III. Visual Observation of the B Supergiant

Spectra of the B supergiant associated with AFGL2636 were taken with the "gold" spectrograph, scanning plateholder and RCA three-stage image tube on the 4-meter telescope at Kitt Peak National Observatory. At a dispersion of 79 Å/mm absorption lines of hydrogen and HeI, are seen and two OII λ4320-4350 feature near Hλ may be present. The interstellar λ4430 feature is strong and there are no emission lines in the spectrum. On the basis of its spectral characteristics and by comparison with galactic standards, the approximate spectral type of the B supergiant is B1-B2I.

A red to near-infrared spectrum obtained with the spectrograph and extended-red S25 image tube of the O'Brien 30-inch telescope shows the Paschen series of hydrogen in absorption and weak emission at Hα and [NII] $\lambda\lambda$6548 and 6583. This emission most likely arises from the background HII region.

UBVR photometry (See Table 1) for this star was obtained using the Mark I "computer" photometer and a RCA Ga-AS 31034 phototube on the 84-inch (2.1 meter) telescope at KPNO.

The B supergiant associated with AFGL2636, appears fuzzy and elongated on the Sky Survey blueprint and it may either be more than one star or surrounded by nebulosity.

The visual photometry can be combined with the spectral type [illegible] the reddening and distance to the B supergiant. The [illegible] 2.0 mag corresponding to a visual extinction [illegible] the calibration by Walborn (1972) [illegible] of a B1-B2 supergiant is M^V = -5.4 to -7.0 leading to a distance range of 3.7 to 7.6 kpc. However, this object is in the direction of the Cygnus spiral feature where reddening is high. Very few spiral tracers are observed more than 2 or 3 kpc from the sun in this direction. Therefore a distance of 7 kpc seems rather high. It is also possible that the UBVR photometry is contaminated somewhat by emission from the NII region so that the colors are too blue. Thus, the visual extinction is probably larger than 6 mag and the distance smaller. Consequently, 4 kpc seems a reasonable upper limit to the distance of AFGL2636. Wendker (1970) has established a lower limit to the distance to G82.6 + 0.4 of 2 kpc. We assume a distance of GL2636 of 4 kpc in the discussion that follows.

IV. Positions of the GL2636 Infrared Sources

Photometric positions of the infrared sources in the GL2636 complex were measured using the Wyoming infrared photometer with a 4.5" beam on the Wyoming Infrared Telescope. Errors in these positions, which are given in Table 2, are estimated to be $\pm$ 1". Included in Table 2 are the positions of GL2636 as given by Price and Walker (1976), the 2695 MHz continuum source G82.6+0.4 (Wendker, 1970), and the luminous B supergiant lying 15" $\pm$ 1" south and 15" $\pm$ 1" east of GL2636 IRS1.

We conclude on the basis of the errors associated with these positional measurements that GL2636 is in fact composed of the IRS1-IRS2 complex and its surrounding nebulae and that G82.6 +0.4 is associated with GL2636.

This presumption is strengthened by the fact that the inegrated 20μ flux from the nebula shown in figure 1d is ~220 jy. Price and Walker (1976) report the 20μ flux from GL2636 as 360 $\pm$ 100 jy. It is evident from the data presented in Table 1 that the B supergiant contributes negligibly to the 2.3-10μ flux from the GL2636 complex.

V. Discussion

The new infrared observations suggest that the GL2636 complex may be a region of active star formation similar in nature to the [1]-BNKL complex in the Orion nebula but embedded in a more extensive region of obscuring gas and dust.

Both optical and radio observations place GL2636 within the HII region G82.6 + 0.4 lying at the Northeastern edge of the Cygnus-X region (see Kleinmann et al., 1979). Our coordinates for IRS1, IRS2, and the B supergiant are, within the observational errors quoted in Table 2, consistent with the position of G82.6 + 0.4 given by Wendker (1970). Wendker (1970) and Terzian and Parrish (1973) have concluded that G82.6 + 0.4 is a compact HII region based upon the fact that the 9.5mm and 11cm radio observation are consistent with thermal bremsstrahlung from an optically thin plasma and because a knot of visible Hα emission is coincident with the radio source (see Dickel, Wendker, and Beintz, 1969).

Wendker (1970) and Terzian and Parrish (1973) noted that no early type exciting stars were known to be coincident with or near G82.6 + 0.4 and the other resolved Cygnus-X radio sources. Wendker suggested that the exciting stars might escape detection if they were in very young HII regions and therefore still hidden in the surrounding dust. In addition, he noted that because generally high absoprtion values occur in Cygnus-X, searches for luminous early type stars require deep magnitude limits.

We conclude that the B1-2Ia supergiant, IRS1, and possibly IRS2 are luminious young stars which are providing the ionizing flux for the G82.6 + 0.4 HII region. Assuming a distance of 4 kpc for the star (see Section III), the dereddened energy distribution shown in Figure 2 yields a luminosity of $\sim 5 \times 10^4 L_\odot$. Campbell (1979) has measured a flux of 500 jy from GL2636 at 100μ. Presumably this data point refers primarily to IRS2 and the surrounding nebulosity and leads to the conclusion that the energy from the GL2636 complex is radiated primarily at a color temperature of ~85° K (See Figure 2). If GL2636 also lies at 4 kpc, it can be seen from Figure 2 that its luminosity is comparable to that of the B supergiant ($\sim 5 \times 10^4 L_\odot$). The infrared spectrum of IRS1, shows evidence of a deep 10μ silicate absorption feature and is very similar to that of the BN object in Orion (see Gillett and Forest, 1973). The cool spectrum of IRS2 is similar to that of the KL nebula in which BN is embedded. IRS1 may well be a luminous young star that is heating a knot of dust at the position of IRS2 as well as an extended region of low density dust which defines the GL2636 nebula. In addition there could be an additional luminous newly formed star at the position of IRS2.

Presumably the B supergiant is more evolved and has dissipated much of the gas and dust from its protocloud as have the θ^1 stars in Orion. The [3.6] - [11.4] color of the supergiant is ≤1.1 mag suggesting that little, if any dust remains around it. The stars in the GL2636 nebula are more recently formed and, as in the case of the BN object in Orion, are still embedded in a dense dust cocoon. Although the 2-4μ spectrum of IRS1 shows no evidence of the H_2O

ice absorption line at 3.05μ that is observed in the BN object, a 3.3μ emission feature is present. This unidentified feature has been observed in the spectra of objects associated with ionized gas (see Merrill et al., 1975). The ice absorption and 3.3μ feature may be characteristic of rather limited evolutionary phases and this subtle difference between the IRS1 and BN spectra may simply indicate a difference in age. Alternatively, the 3.3μ emission could result from contamination of the IRS1 spectrum by the emission from the surrounding HII region in the large 17" spectrometer beam. The 3.3μ feature has been observed in the shock front south of the θ^1 nebula in M42 (Jones, 1978).

We close with a comment about the position of GL2636 within the Cygnus-X region. As is evident from Figure 4 in Kleinmann et al. (1979), GL2636 and all the other anonymous AFGL sources in the Cygnus-X region are associated with Wedken's (1970) resolved 11 cm HII regions which presumably represent local density enhancements in the interstellar medium. If the distance to GL2636 is as low as 2 kpc, it is close enough to have been affected by the shock front from Cygni Supernova. On the other hand, if the distance to GL2636 is as great as 4-6 kpc, it will lie on the inner edge of the Perseus arm. If this is the case it may be a region of star formation that was triggered by the passage of a spiral density wave. Thus, a more accurate determination of the distance to GL2636 may allow us to identify the physical processes which triggered its formation.

Acknowledgements

The Wyoming group wishes to thank Steve Mason for assistance with the measurements. Robert D. Gehrz, John A. Hackwell, and Gary Grasdalen acknowledge financial support from the U. S. Air Force, ONR, the National Science Foundation, and the State of Wyoming.

H. E. Smith assisted with the observations at Lick Observatory. SPW acknowledges support from NSF and the U. S. Air Force.

Table 1. Infrared Magnitudes for the Sources Associated With AFGL 2636

OBJECT	UT DATE	PHOTO-METER	TELE-SCOPE	BEAM DIA-METER	[1.25]	[1.65]	[2.3]	[3.6]	[4.9]	[8.7]	[10]	[11.4]	[12.6]	[18]	[15.5]	Notes
GL2636, IRS 1	1978 JUN 6	(1)	(4)	17"	-----	+8.76	+6.97	+5.34	----	----	----	----	-----	-----		
	1978 JUN 12	(1)	(4)	17"	-----	-----	+7.07	-----	----	----	----	----	-----	-----		
	1978 SEP 29	(1)	(4)	17"	-----	+8.66	+7.02	+5.30	-----	----	----	----	-----	-----		
	1978 OCT 3	(1)	(4)	17"	-----	+8.95	+7.18	+5.53	-----	----	----	----	-----	-----		
	1978 OCT 9	(1)	(4)	17"	+10.31	+8.72	+6.94	+5.43	-----	----	----	----	-----	-----		
	1978 OCT 10	(2)	(4)	9"	-----	-----	+6.90	+5.32	+4.23	+1.96	+2.20	----	+1.55	-0.11	-----	
	1979 JUL 3	(1)	(4)	9"	+9.72	+8.84	+7.05	+5.29	-----	-----	----	----	-----	-----	-----	
	1979 JUL 25	(1)	(5)	7.5"	-----	-----	-----	+5.42	-----	-----	----	----	-----	-----	-----	
	1979 AUG 4	(3)	(6)	4.5"	-----	-----	+7.16	+5.46	+4.21	+2.60	+2.28	+2.12	+1.55	-----	-----	
	1979 AUG 5	(3)	(6)	4.5"	-----	-----	-----	-----	-----	-----	+2.42	----	-----	-----	-----	
	1979 AUG 10	(3)	(6)	4.5"	-----	-----	-----	+5.59	+4.52	-----	+2.31	----	-----	-----	+0.13	
GL2636, IRS 2	1978 OCT 10	(2)	(4)	9"	----	-----	-----	+8.11	+6.57	+2.71	+2.68	----	+1.50	-1.57	-----	
	1979 AUG 4	(4)	(6)	4.5"	----	-----	+10.45	+8.35	+6.38	+3.33	+2.87	+2.63	+2.05	-----	-1.71	
	1979 AUG 5	(3)	(6)	4.5"	----	-----	-----	-----	-----	-----	----	----	-----	-----	-1.9[illegible]	
	1979 AUG [illegible]	(2)	(6)	4.5"	----	-----	-----	+8.03	+6.61	-----	----	----	-----	-----	-1.7[illegible]	
B SUPER-GIANT	[illegible]				----	-----	-----	------	-----	-----	----	----	-----	-----	-----	(7)
	[illegible]	(1)	(4)	9"	+9.[illegible]	+[illegible].62	+[illegible].13	+8.11	-----	-----	----	----	-----	-----	-----	
	[illegible]	(1)	(5)	7.5"	+9.14	-----	-----	-----	-----	-----	----	----	-----	-----	-----	
	[illegible]	(3)	(6)	4.5"	-----	-----	+[illegible].67	+[illegible].09	----	-----	+7.[illegible]	----	-----	-----	-----	

Notes to Table 1

(1) UM-UCSD InSb photometer (See Gosnell, Hudson and Pueter, 1979 for a description.)

(2) UM multifilter bolometer (See Gallagher and Ney, 1976 for details).

(3) UW multifilter bolometer (See Gehrz, Hackwell, and Jones, 1974 for details concerning the effective bandpasses and calibration).

(4) UM-UCSD Mt. Lemmon Infrared Observatory 152cm telescope.

(5) Lick Observatory 305cm telescope.

(6) Wyoming Infrared Observatory 234cm telescope.

(7) This supergiant is 15" ± S and 15" ± 1"E of AFGL2636, IRS1.

Table II: Positions of Sources Associated With GL 2636

Source	$\alpha(1950)$	$\delta(1950)$	Notes
GL2636	$20^h40^m42^s\pm14^s$	$+42°46'42''\pm90''$	Price and Walker 1976
G82.6 + 0.4	$20^h40^m54^s\pm6$	$+42°47'00''\pm60''$	Wendker, 1970
IRS1	$20^h40^m47^s.32\pm.09^s$	$+42°45'58''.8\pm1''$	Wyoming Photometic Position
IRS2	$20^h40^m46^s.64\pm.09^s$	$+42°45'58''.8\pm1''$	Wyoming Photometic Position
B Supergiant	$20^h40^m48^s.68\pm.09^s$	$+42°45'46''.3\pm1''$	Wyoming Photometic Position

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MAILING ADDRESSES

R. D. Gehrz, J. A. Hackwell, and G. L. Grasdalen

Department of Physics and Astronomy

University of Wyoming

University Station

Box 2905

Laramie, WY 82071

R. M. Humphreys and K. M. Merrill

Astronomy Department

University of Minnesota

116 Church Street. S. E.

Minneapolis, MN 55455

Richard C. Puetter and S. P. Willner

Physics Department

University of California at San Diego

C-011

LaJolla, CA 92093

R. W. Russell

Department of Astronomy

Cornell University

Ithaca, NY 14853

Figure Captions

Figure 1: Figures 1a)-d) show isphotal contours of the infrared radiation from AFGL 2636 at effective wavelengths of 3.6μ, 4.9 μ, 10μ(N band), and 19.5μ(Q band). The maps were made using a Wyoming multifilter infrared photometer (see Gehrz, Hackwell, and Jones, 1974) with a 4.5" diameter beam (3.74×10^{-10} sr) on the 234 cm Wyoming infrared Telescope. The beams were thorwn 33" between centers. Contours are in units of 10^{-9} W-cm^{-2}-μ^{-1}-sr^{-1}. The point like sources IRS1 and IRS2 are 3" apart. The 4.5" beam is 2.6λ/D in diameter at 19.5μ on the 234cm telescope.

Figure 2: Broadband photometric measurements of the infrared sources associated with AFGL 2636. The majority of the infrared radiation from AFGL 2636 is seen to be emitted at a color temperature of [illegible]°K and is mainly associated with the source IRS2. Both IRS1 and IRS2 show the 10μ silicate absorption feature and the broadband 1.25μ -20μ energy distribution of IRS1 resembles that of the BN object in Orion. The luminosity of the B1-2Ia supergiant 15"S adn 15"E of IRS1, which has been dereddened using A_V 6 mag (Humphreys, 1979) is comparable to the luminosity of the IRS1-IRS2 complex.

Figure 3: The 2-4μ 2% resolution spectrum of AFGL 2636 made by Gosnell et al. (1979) with a 17" beam is shown compared to 2.3μ and 3.6μ broadband measurements of IRS1 with a 4.5" beam. The comparison suggests that the narrow band spectrum refers mainly to IRS1 with minimal contamination from other sources in the vicinity. Merrill et al. 1975 originally discovered the unidentified 3.3μ emission feature in the planetary nebula NGC 7027.

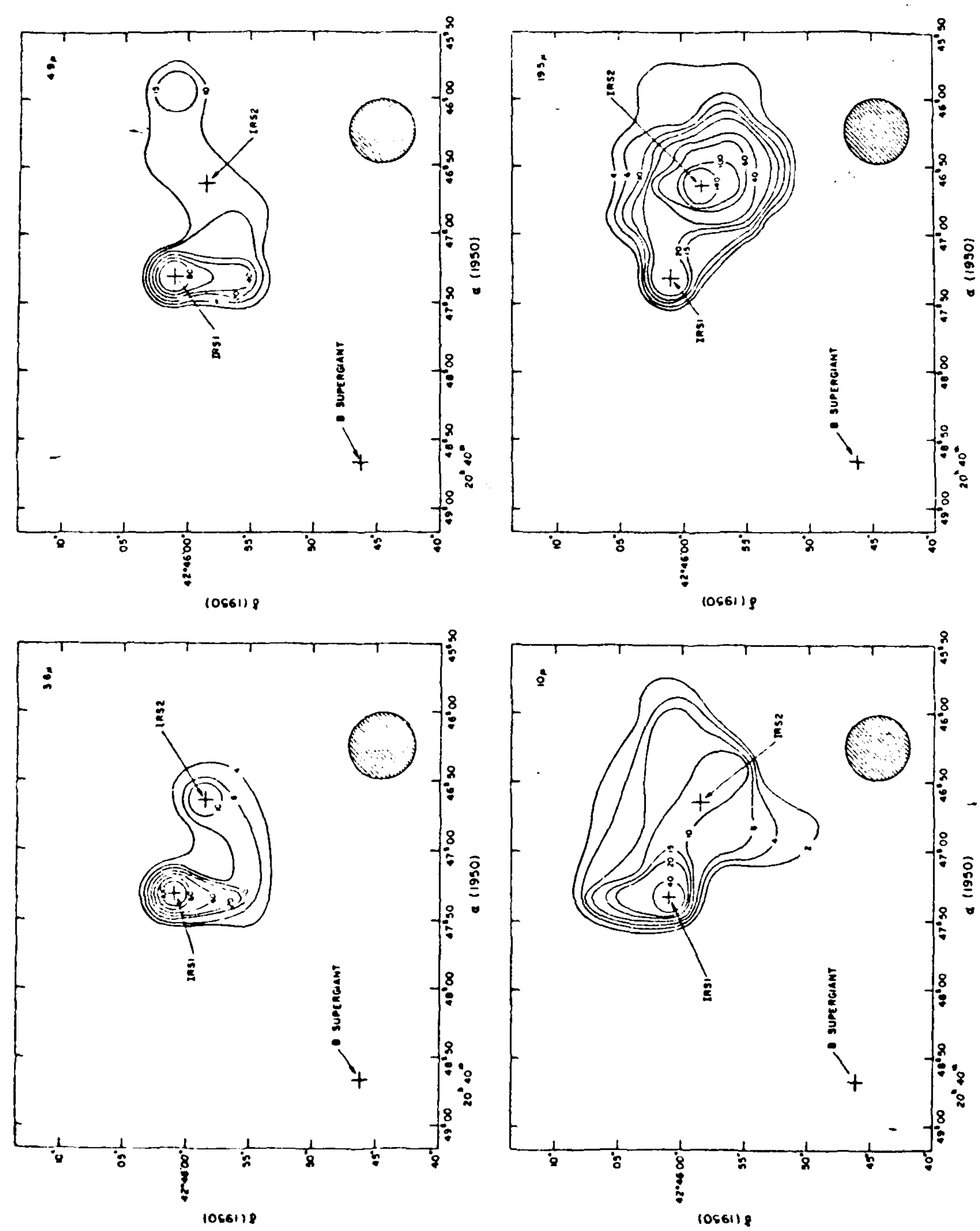


Figure 1

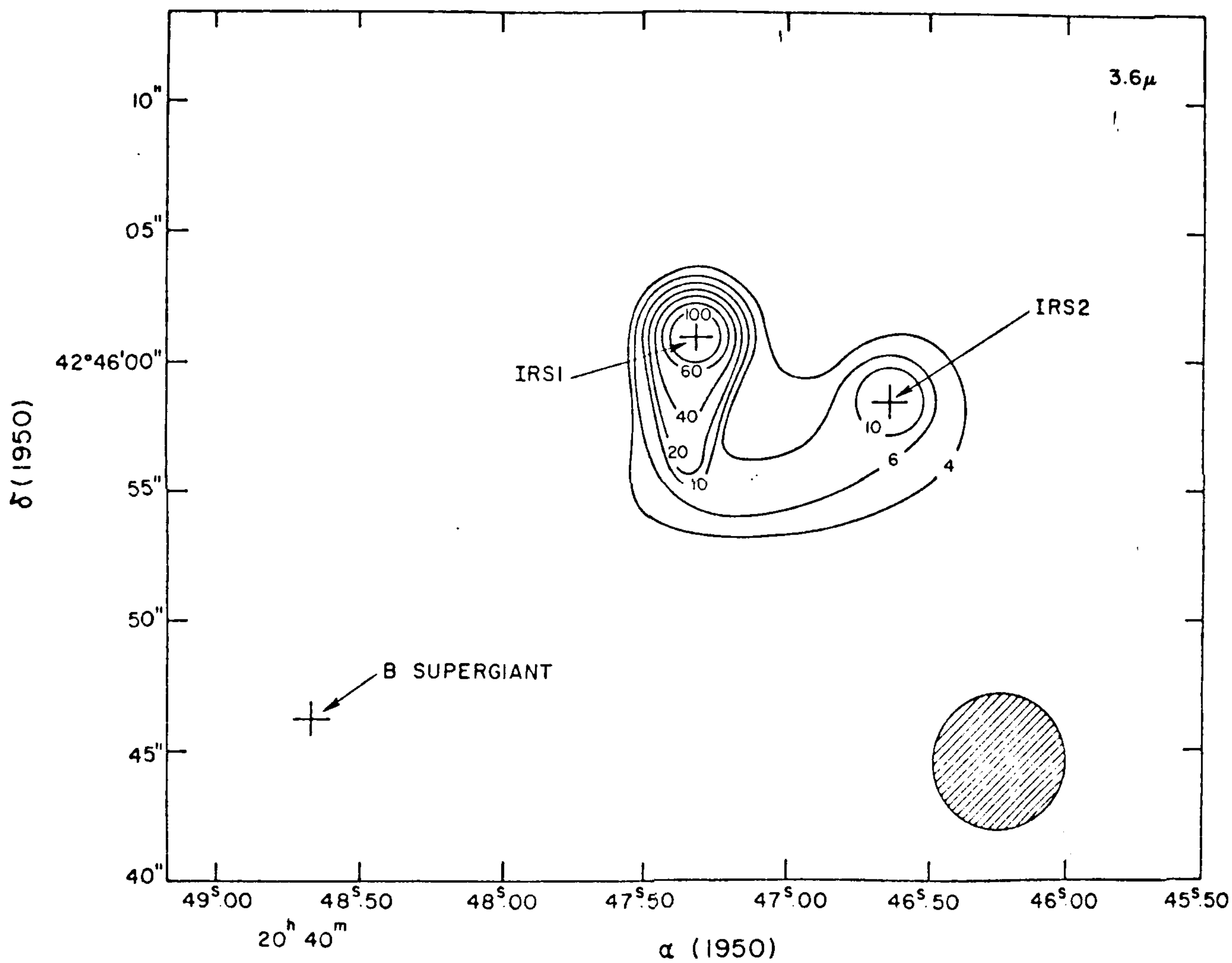

3.6μ
IRS2
IRS1
100
60
40
20
10
10
6
4
B SUPERGIANT
10"
05"
42°46'00"
55"
50"
45"
40"
δ (1950)
49s00
48s50
48s00
47s50
47s00
46s50
46s00
45s50
20h 40m
α (1950)

Figure 1a)

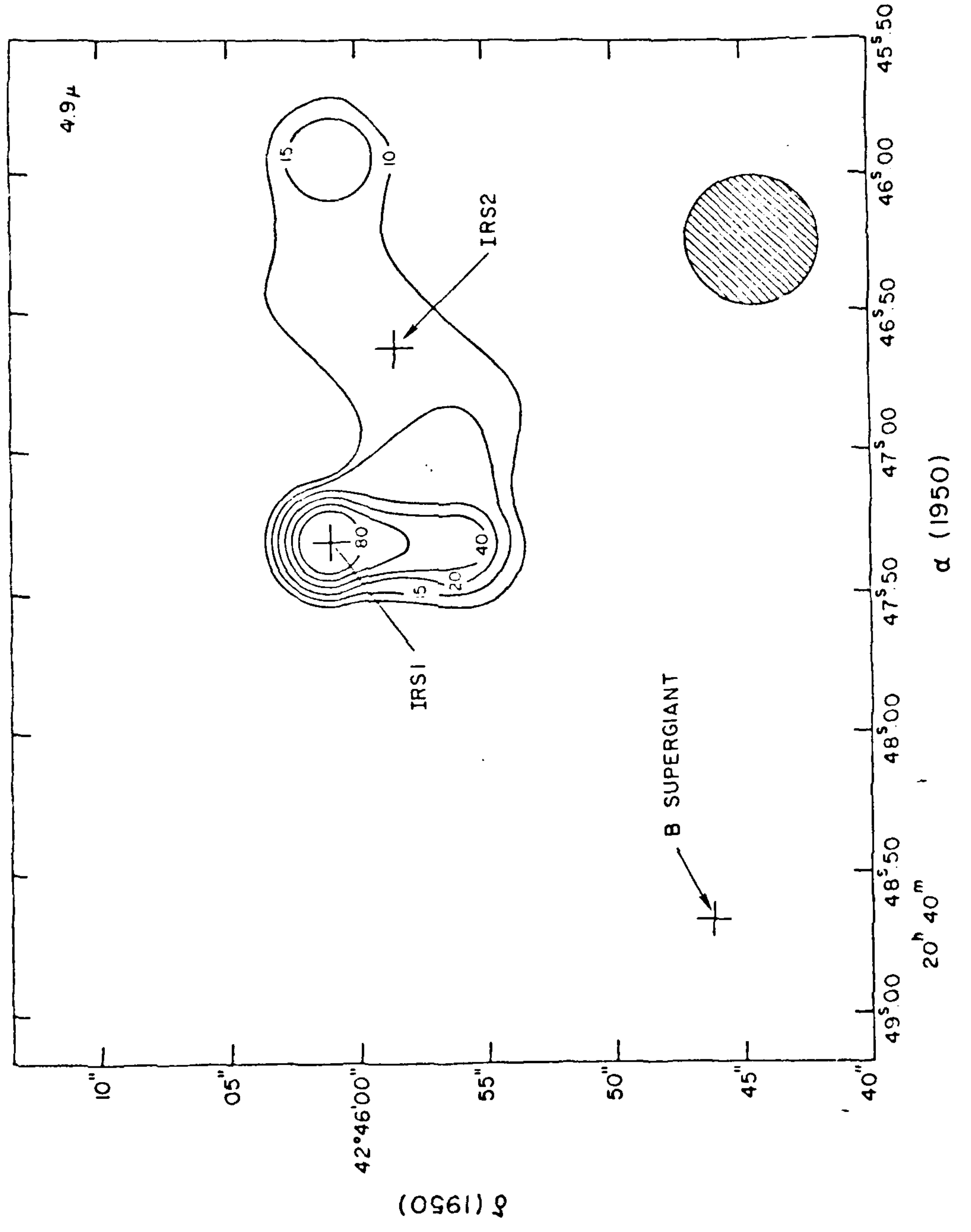

4.9μ
15
10
IRS2
80
40
20
15
IRS1
B SUPERGIANT
10"
05"
42°46'00"
55"
50"
45"
40"
δ (1950)
49s.00
20h40m
48s.50
48s.00
47s.50
47s.00
46s.50
46s.00
45s.50
α (1950)

Figure 1b)

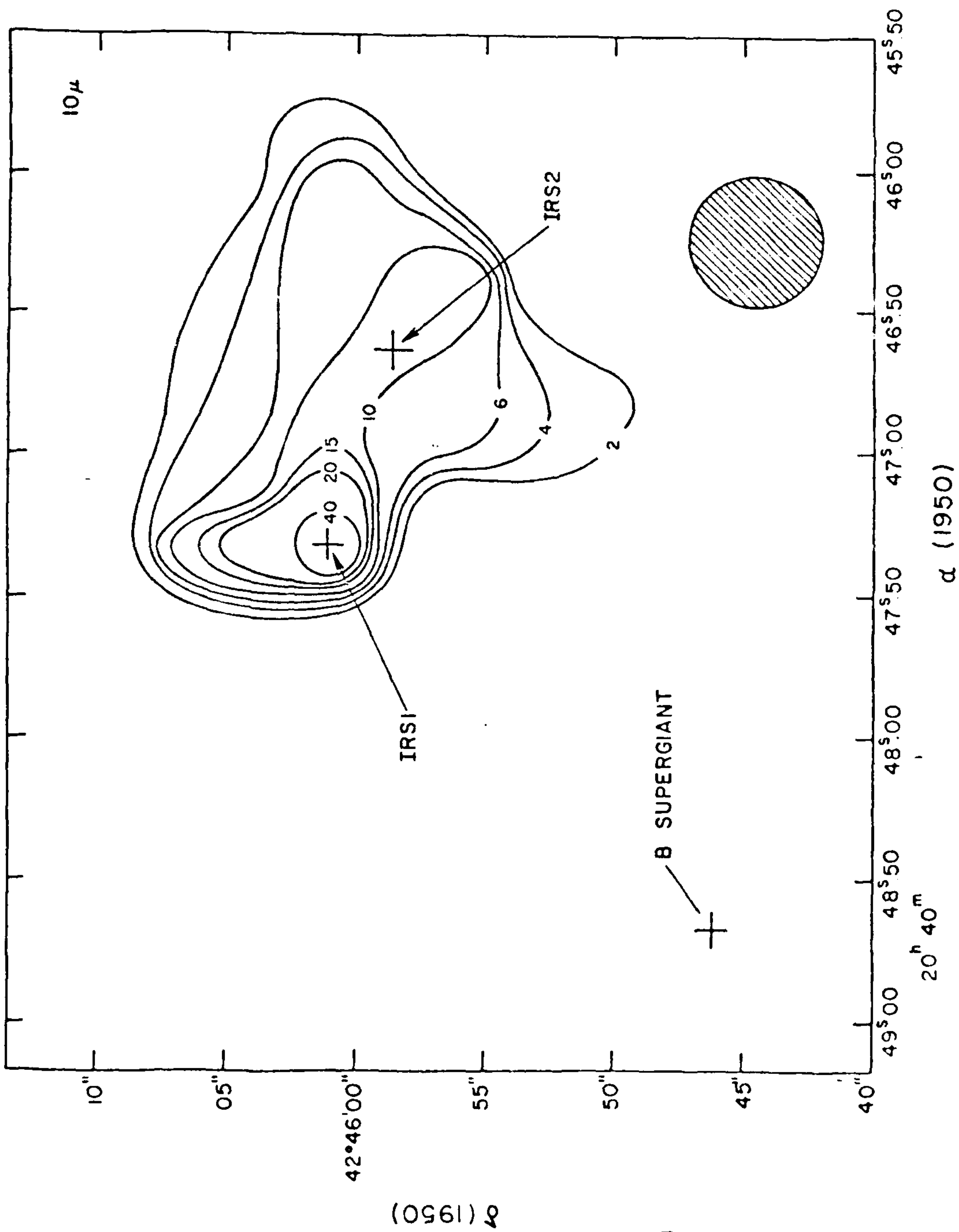

10μ
IRS2
IRS1
B SUPERGIANT
40
20
15
10
6
4
2
45s50
46s00
46s50
47s00
47s50
48s00
48s50
49s00
20h 40m
α (1950)
10"
05"
42°46'00"
55"
50"
45"
40"
δ (1950)

Figure 1c)

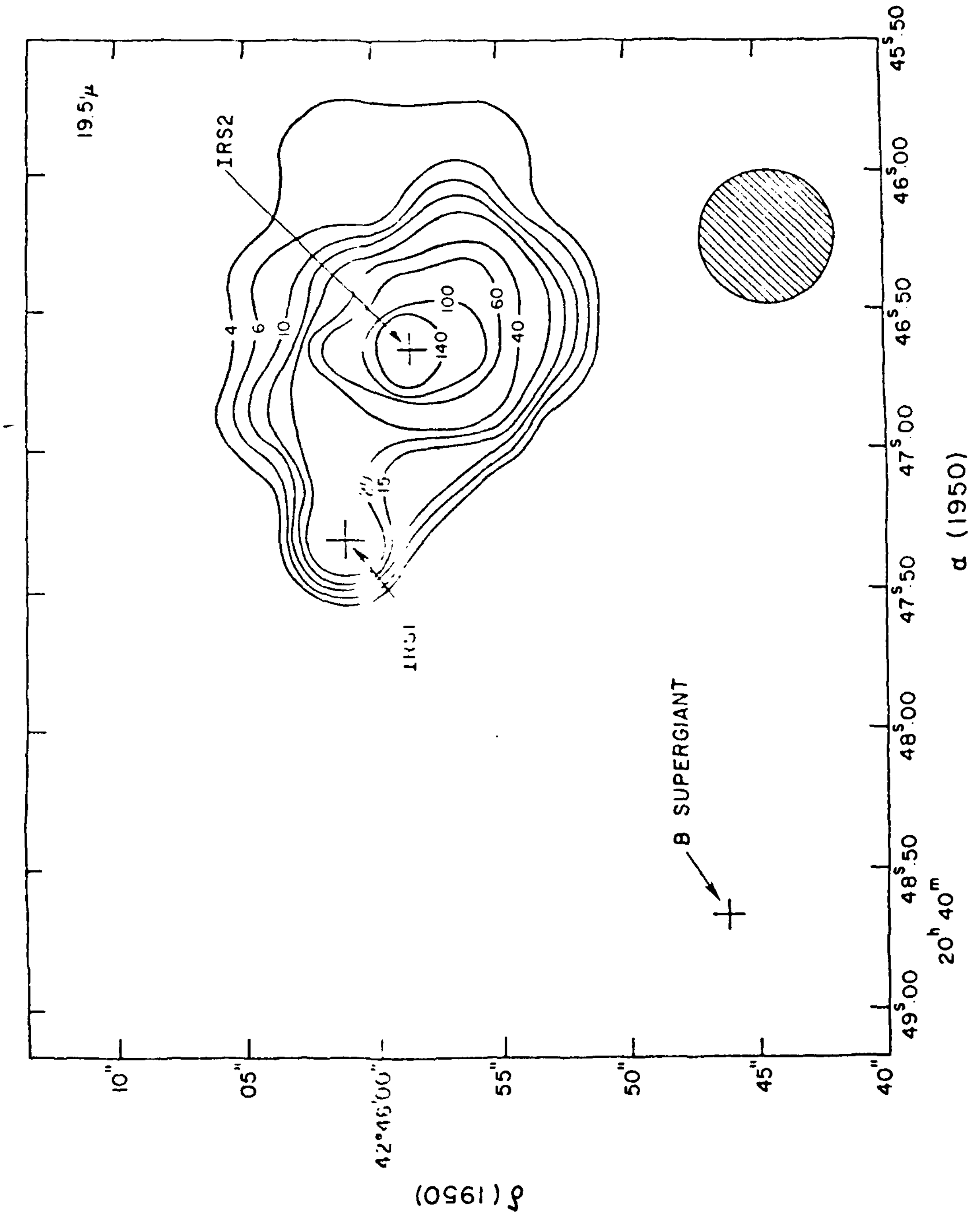
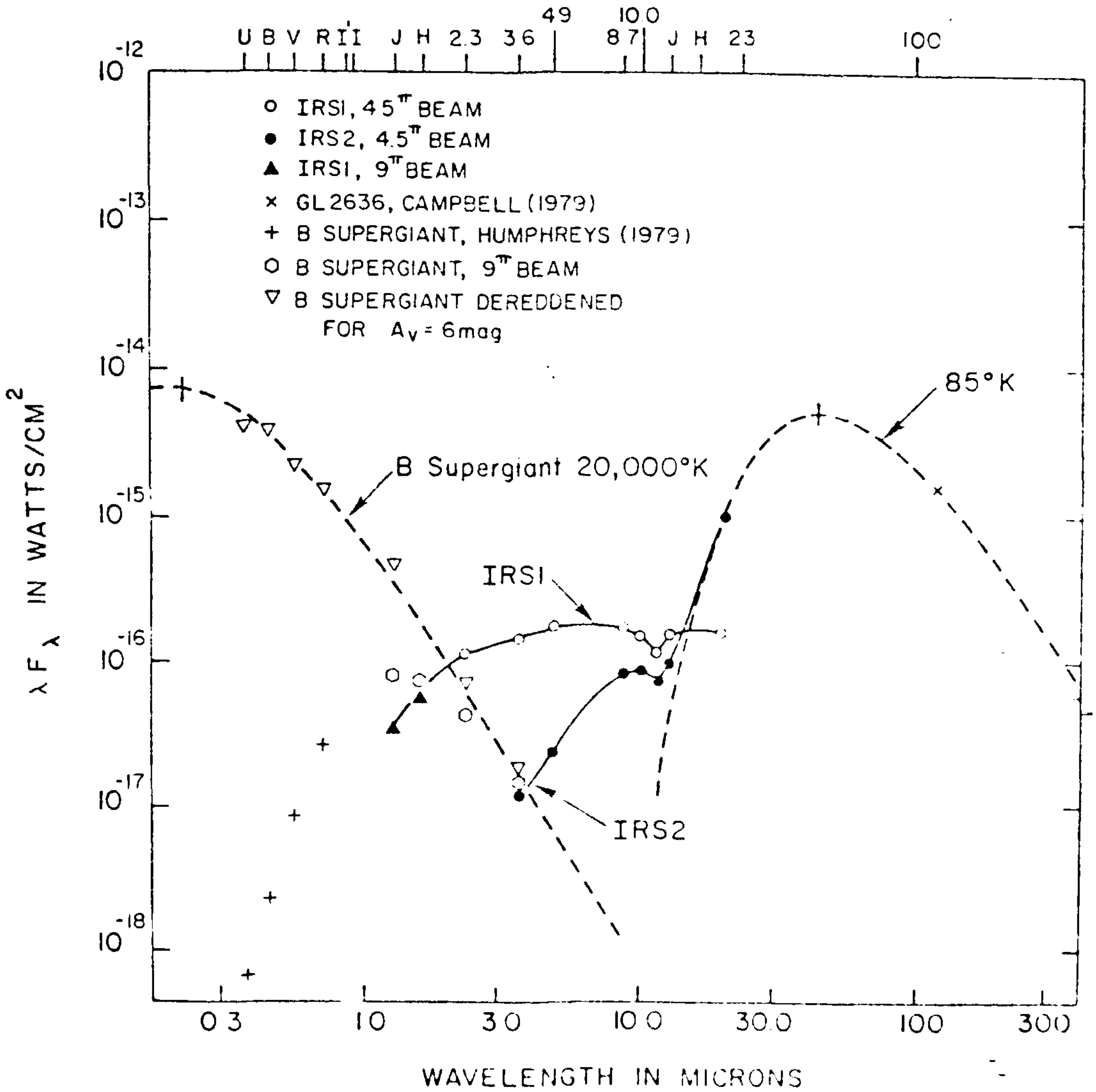
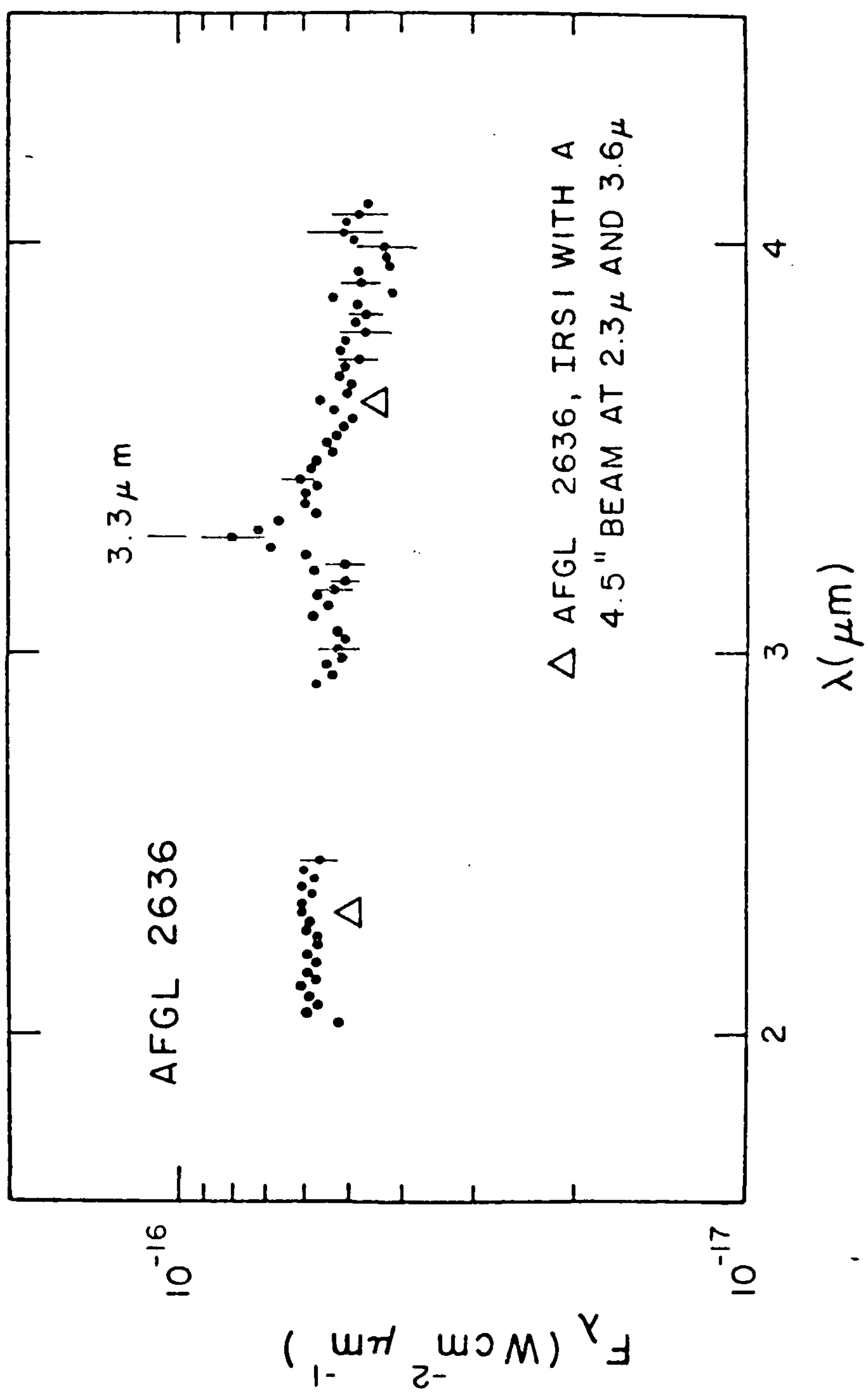

19.5μ
IRS2
IRS1
B SUPERGIANT
4
6
10
15
20
40
60
100
140
45ˢ.50
46ˢ.00
46ˢ.50
47ˢ.00
47ˢ.50
48ˢ.00
48ˢ.50
49ˢ.00
20ʰ40ᵐ
α (1950)
10"
05"
42°46'00"
55"
50"
45"
40"
δ (1950)

Figure 1d)



U B V R I I J H 2.3 3.6 4.9 8.7 10.0 J H 23 100
o IRS1, 4.5" BEAM
● IRS2, 4.5" BEAM
▲ IRS1, 9" BEAM
× GL 2636, CAMPBELL (1979)
+ B SUPERGIANT, HUMPHREYS (1979)
O B SUPERGIANT, 9" BEAM
▽ B SUPERGIANT DEREDDENED FOR A_V = 6mag
B Supergiant 20,000°K
85°K
IRS1
IRS2
λF_λ IN WATTS/CM^2
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
0.3 1.0 3.0 10.0 30.0 100 300
WAVELENGTH IN MICRONS

Figure 2.



AFGL 2636
3.3 μm
△ AFGL 2636, IRS1 WITH A
4.5" BEAM AT 2.3μ AND 3.6μ
2
3
4
λ(μm)
10^{-16}
10^{-17}
F_λ (W cm^{-2} μm^{-1})

Figure 3.

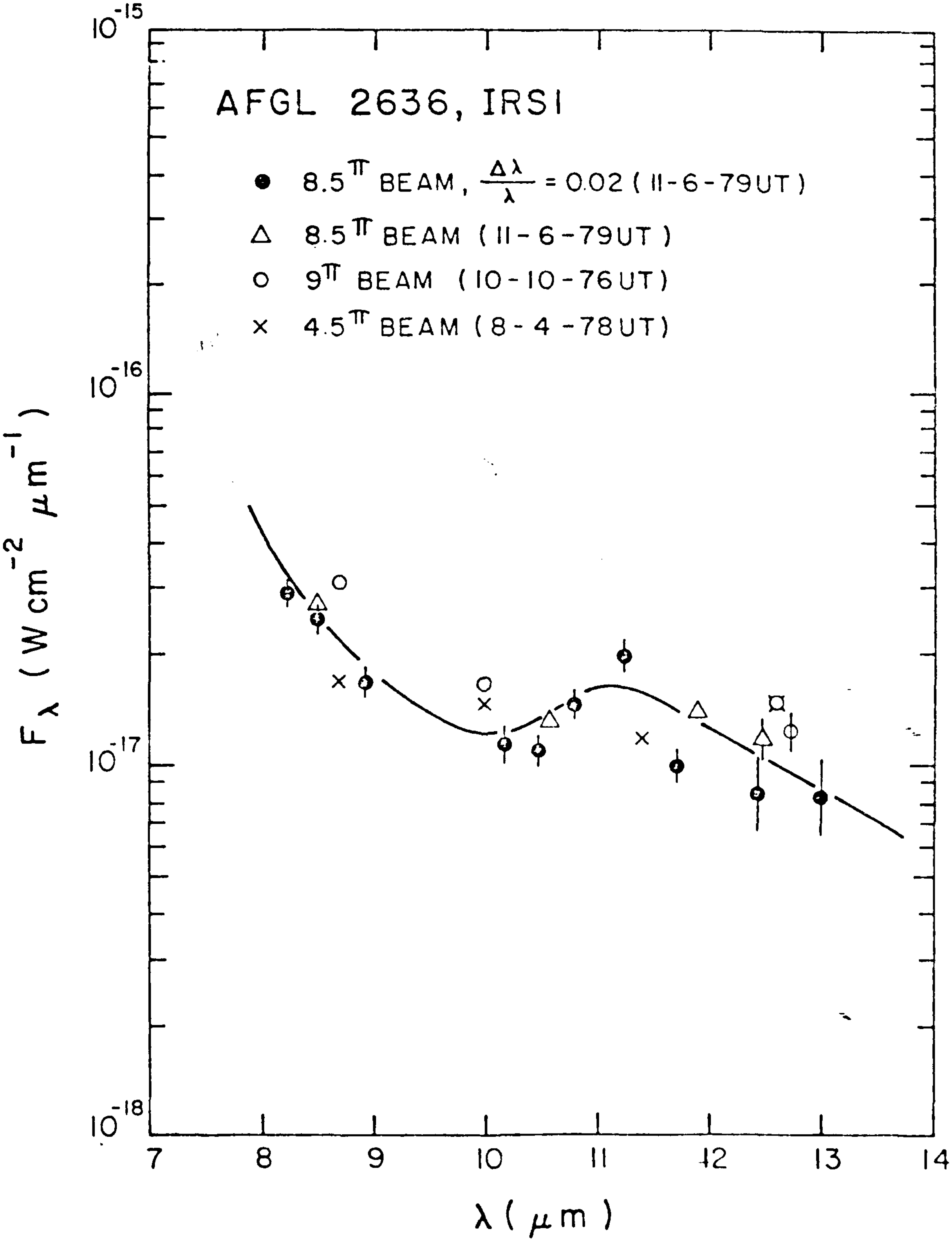

AFGL 2636, IRS1
8.5" BEAM, Δλ/λ = 0.02 (11-6-79UT)
8.5" BEAM (11-6-79UT)
9" BEAM (10-10-76UT)
4.5" BEAM (8-4-78UT)
F_λ ($W cm^{-2} \mu m^{-1}$)
10^{-15}
10^{-16}
10^{-17}
10^{-18}
7
8
9
10
11
12
13
14
λ (μm)

Figure 4.